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RESEARCH ARTICLE

Reconstructed organic rice fields: Effects on soil organic carbon, total nitrogen, their mineralization, and rice yield in Japanese Andosols

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Highlights

- Terrace land reconstruction significantly influenced rice yields between opposing sides of the newly established fields.
- Soil organic carbon, total nitrogen, and their decomposition dynamics underwent modifications due to land reconstruction, specifically in the 15–30 cm subsurface soil layer.
- The fertility of soil extending to a depth of 30 cm served as a crucial determinant of rice productivity following reconstruction.

Abstract

To examine the impact of anthropogenic land reconstruction, particularly the consolidation of small terraces into larger fields, on soil organic carbon (SOC), total nitrogen (TN) dynamics, rice yield, and its components, soil and plant samples were collected from seven newly reconstructed fields in Japanese Andosols in Tochigi, Japan. Samples were obtained from both the former low- and high-elevation sides within each field plot. During harvest season, nine rice plants were randomly selected from each plot (0.675 m^2, comprising 3 rows and 3 hills per row), collected from a 3-m stretch along both the east (former low side) and west (former high side) ridges. Soil cores were collected from identical plots at two depths (0–15 and 15–30 cm) and combined into one composite sample per layer. Rice plant samples were air-dried for two weeks until reaching constant moisture content, after which stems and ears were separated and weighed to determine biomass, yield, yield components, and nitrogen uptake. This indicated that land reconstruction significantly affected rice yield and its components between the two sides of all field plots. SOC, TN, and their decomposition following land reconstruction showed notable changes, especially in the 15–30 cm subsurface soil layer. Additionally, grain weight demonstrated significant correlation with SOC, TN, and carbon decomposition in both the 0–15 and 15–30 cm layers, indicating that soil fertility to a depth of 30 cm was crucial for rice productivity after land reconstruction.

Keywords: Japanese Andosols, different soil layers, organic rice farming, reconstructed fields, rice yield

1. Introduction

Japan's landscape is primarily mountainous, characterized by steep slopes and approximately two-thirds forest coverage, resulting in limited agricultural space. Merely 15% of the land is sufficiently flat and suitable for farming, including lowland rice cultivation (Amano 1985). Rice paddies in Japan typically occupy ravine-like areas, forming a distinctive landscape in traditional Japanese farming villages known as Yatsuda (Kurniawan *et al.* 2021). In certain regions of Japan, including central areas such as Tochigi Prefecture, agricultural

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fields remain small due to altitude variations. These size constraints reduce agricultural machinery efficiency and management. Land reconstruction seeks to optimize field management by adjusting field dimensions and leveling terrain. However, such modifications inevitably result in soil disturbance. Research indicates that mechanical disturbance affects soil properties, including soil organic carbon (SOC), total nitrogen (TN), aggregate size, bulk density, porosity, hydraulic conductivity, permeability, nutrient dynamics, and greenhouse gas emissions (Dexter 1997; Steinmann 2002; Blanco-Canqui *et al.* 2005; Peterson *et al.* 2019).

Volcanic ash soils, known as Andosols, constitute approximately 27% of Japan's total agricultural land, encompassing about 1.35 million hectares (Takahashi and Shoji 2002). Andosols are distinguished by their low bulk density, high phosphorus retention, and high contents of SOC and TN (Batjes 1996; Nanzyo 2002; Shirato *et al.* 2004). Active aluminum (Al) and iron (Fe), which form stable complexes with humus, primarily influence the SOC content (Wada and Higashi 1976; Nanzyo 2002; Miyazawa *et al.* 2013). While Andosols cover only 0.75% of the Earth's surface, they account for 1.75% of global soil carbon storage, exhibiting higher SOC stability compared to other soil types (Hillel and Rosenzweig 2009). Studies indicate that Andosols possess a high TN content of 31.0 kg m^{-2} at a soil depth of 200 cm (Batjes 1996), suggesting that their elevated N content benefits agriculture, particularly rice cultivation (Shoji *et al.* 1986). In conventional Japanese rice production, which employs agrochemicals including synthetic fertilizers, herbicides, and pesticides, rice yields typically achieve approximately six tons per hectare in most paddies, including those on Andosols (FAO 2024).

The implications of landfilling and field leveling on SOC, TN, and their effects on plant growth are acknowledged but remain insufficiently studied, particularly in organic rice cultivation systems. Soil disturbance manifests through various mechanisms, including tillage operations, substantial organic matter incorporation as carbon input, moisture-induced drying and rewetting cycles, hydrological modifications, land-use changes, vegetation alterations, wildfires, permafrost, and climate warming (Toriyama *et al.* 1988; Franzluebbers *et al.* 2000; Grosse *et al.* 2011; Tanaka *et al.* 2012; Deng *et al.* 2014; Cheng *et al.* 2016; Takakai *et al.* 2020). However, to the best of our knowledge, research specifically examining disturbances from landfilling and leveling activities remains absent from the literature. This study was initiated to evaluate the effects of soil disturbance from land reconstruction on SOC, TN, their mineralization, and rice growth across three consecutive years. The findings aim to enhance understanding of soil nutrient dynamics, rice growth, and yield in reconstructed organic rice fields in Japan.

2. Materials and methods

2.1. Experimental site

The research field is located in Sagawano, Nogi machi, Shimotsuga District, Tochigi Prefecture, Japan (36°14´N and 139°46´E). Land reconstruction through landfilling and leveling was implemented to expand field dimensions. Initial reconstruction commenced in winter 2013 at a riverside location, designated as the low-elevation site. Reconstruction extended to a hillside location farther from the river in winter 2015, designated as the high-elevation site (Appendix A). The field elevations at the high-elevation site (west) and low-elevation site (east) measure 24.3 and 20.7 m above sea level, respectively (Appendix B-a). The reconstruction transformed former four-step terraced paddy fields into two steps, creating larger fields (100 m in length and 30 to 80 m in width). Field leveling required backfill transport from west to east, establishing four treatments: high east (HE) and high west (HW), each replicated three times in high-elevation fields, and low east (LE) and low west (LW), each replicated four times in low-elevation fields (Appendix B).

2.2. Soil and plant analysis

During rice harvest seasons on September 29th, 2016; September 19th, 2017; and September 22nd, 2018, nine plants were randomly selected from each plot (0.9 m×0.75 m= 0.675 m^2, comprising three rows and three hills per row) along 3-m stretches of both east (former low side) and west (former high side) ridges. Three soil cores were collected and combined into one composite sample for both surface (0–15 cm) and subsurface (15–30 cm) layers within identical plots. Soil sampling continued for three consecutive years using a core soil sampler. The samples were processed by removing visible plant materials and small stones, then air-dried and ground to pass through a 2-mm sieve (Kautsar *et al.* 2020). SOC and TN contents were analyzed *via* dry combustion using a Sumigraph NC 220F analyzer (Sumika Chemical Analysis Service, Ltd., Osaka, Japan). Carbon decomposition rates at 8 weeks were determined by measuring CO_2 and CH_4 production under anaerobic conditions using a gas chromatograph (GC-8A and GC-2014; Shimadzu, Kyoto, Japan). Following gas sample collection, nitrogen mineralization rates were measured by analyzing NH_4^+ concentrations from soil extractions using 10% KCl solution, employing nitroprusside and hydrazine reduction methods consistent with previous studies in the same fields (Cheng *et al.* 2007, 2016; Kautsar *et al.* 2020a, b, 2022). Rice plant samples were air-dried for two weeks until reaching constant water content. Rice stems and ears were separated and weighed to determine biomass, yield, yield components, and N uptake (Cheng *et al.* 2009).

2.3. Statistical analysis

The data underwent analysis of variance (ANOVA) to examine differences among treatments and years. Tukey's honestly significant difference was employed as a post hoc test with a statistical significance level of 5%. Pearson correlation analysis was conducted to evaluate relationships between soil properties and rice yield components. All statistical analyses were performed using SPSS version 26 (IBM Corp., Armonk, New York, USA).

3. Results

3.1. Changes in SOC and TN

SOC contents exhibited no significant differences across the three years for both surface layer (0–15 cm) and subsurface

layer (15–30 cm) in the HE, HW, and LE plots. However, SOC values differed significantly among the three years for both layers in the LW plots (Fig. 1 with lowercase letters), indicating substantial SOC variability in the low-elevation west fields following land reconstruction. Within the same year across the four treatment plots, SOC values in the LE plots were significantly higher than those in the HE and HW plots at surface soil layers. This trend varied in the subsurface layers (Fig. 1 with uppercase letters), suggesting higher soil organic matter content on the low-elevation east side compared to other plots after reconstruction. When comparing SOC values between surface and subsurface layers across the four treatment plots, the SOC difference was more pronounced in the LE than in other plots.

Over the 3-year period, TN values showed no significant differences for the surface layers (0–15 cm) of HE and LE, or for subsurface layers (15–30 cm) of HE, HW and LE. However, TN values varied significantly among the three years in surface layers of HW and LW, and subsurface layers (15–30 cm) of LW (Fig. 2), indicating high TN content variation on the west side of the newly reconstructed fields. In the subsurface soil layers, LE demonstrated the highest TN value, though not significantly different from HE. LW exhibited the lowest TN compared to other fields. The difference in TN values between surface and subsurface layers across the four treatment plots was most pronounced in the LE, similar to the SOC results (Figs. 1 and 2).

3.2. Changes in C decomposition and N mineralization

In surface soil layers during 2016, C decomposition in the low-elevation field plots near a river (LE and LW) exceeded that of high-elevation field plots near hill (HE and HW) significantly (Fig. 3). In 2017, C decomposition in LE at 0.90 g C kg^{-1} maintained the highest value among all plots, significantly exceeding HW, but showing no significant difference from HE and LW. In 2018, the LE plot recorded a significantly higher value of 1.00 g C kg^{-1} compared to HW and LW, but not HE. In the subsurface soil layers, LE consistently showed the highest carbon decomposition value across all three years. In 2016, LE significantly exceeded HE, HW and LW. In 2017, carbon decomposition in LE plots significantly exceeded LW plots. In 2018, LE maintained the highest carbon decomposition, significantly exceeding HW and LW. No significant differences were observed in carbon decomposition across the three years within plots for either soil layer (Fig. 3).

N mineralization values in surface soil layers of LE and LW plots in 2016 significantly exceeded those in HW and HW plots, respectively (Fig. 4). In 2017 surface layers, HW showed significantly lower N mineralization compared to other plots. In 2018 surface layers, LE demonstrated significantly highest values among plots, followed by HE and LW, while HW remained the lowest. Similar patterns emerged in subsurface soil layers, with LE showing the highest N mineralization. While HE and HW plots showed no significant

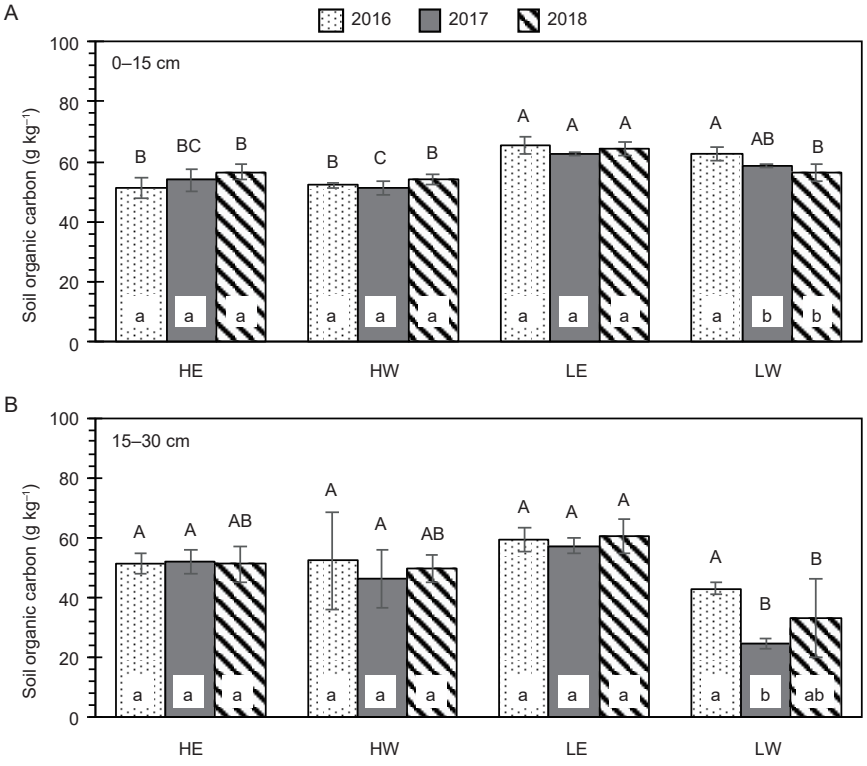


Fig. 1 Soil organic carbon content at depths of 0–15 cm (A) and 15–30 cm (B) in reconstructed rice fields sampled from 2016 to 2018. HE, high-elevation field east side; HW, high-elevation field west side; LE, low-elevation field east side; LW, low-elevation field west side. Values represent mean±standard deviation (n=3 for HE and HW, n=4 for LE and LW). Different uppercase letters denote significant differences among fields within the same year, while lowercase letters denote significant differences among years within the same field, as determined by Tukey's HSD (P<0.05).

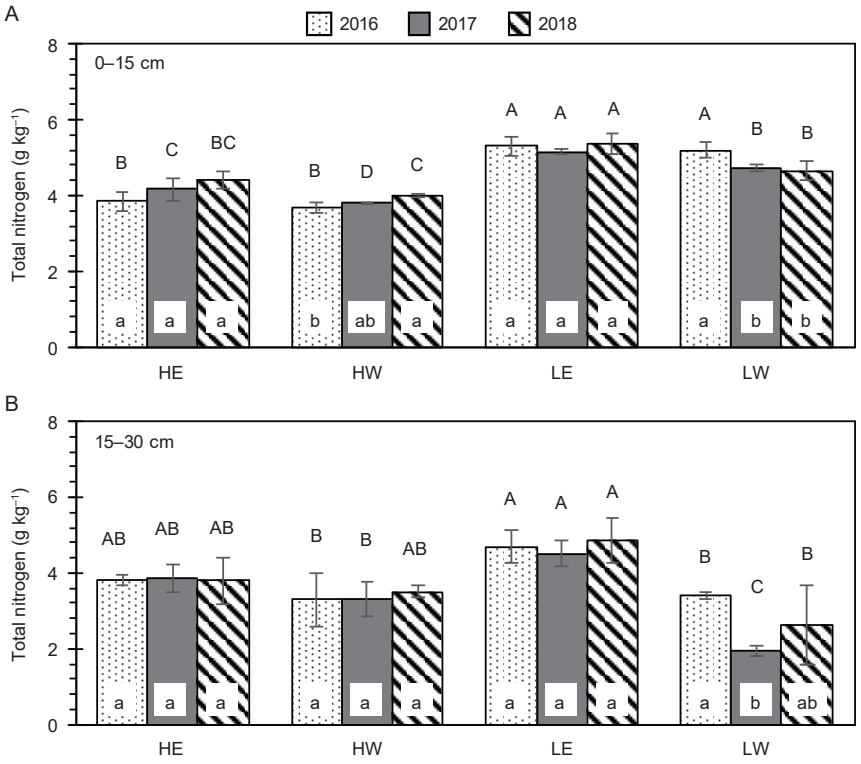


Fig. 2 Total nitrogen content in soil samples collected from reconstructed rice fields at depths of 0–15 cm (A) and 15–30 cm (B) from 2016 to 2018. HE, high-elevation field east side; HW, high-elevation field west side; LE, low-elevation field east side; LW, low-elevation field west side. Values represent mean±standard deviation (n=3 for HE and HW, n=4 for LE and LW). Different uppercase letters denote significant differences between fields within the same year, while lowercase letters indicate significant differences between years within the same field, as determined by Tukey's HSD (P<0.05).

year-to-year differences, nitrogen mineralization in LE and LW exhibited declining trends over time in both surface and subsurface soil layers (Fig. 4).

3.3. Changes in rice yield, yield components and N uptake

Field reconstruction effects on panicle number in 2016 revealed that HE exhibited the highest count, showing significant differences from HW and LW (Table 1). In 2017 and 2018, LE demonstrated significantly higher panicle numbers at 281.94 and 293.52 panicles m^{-2}, respectively, compared to other plots. Panicle numbers in 2017 and 2018 for the remaining plots ranged from 166.96 to 213.11 panicles m^{-2} and 152.67 to 194.24 panicles m^{-2}, respectively. HE and HW plots showed no significant year-to-year variations. LE increased from 167.39 panicles m^{-2} in 2016 to 281.94 panicles m^{-2} in 2017 and 293.52 panicles m^{-2} in 2018. LW exhibited the lowest panicle number at 129.32 panicles m^{-2} in 2017; however, it increased significantly to 202.61 panicles m^{-2} in 2018.

The 1,000-grain weight showed no significant differences among plots in 2016, ranging from 21.89 to 23.65 g (Table 1). In 2017, LE recorded the lowest 1,000-grain weight at 21.23 g, while other plots ranged from 22.94 to 24.06 g. In 2018, HE at 24.78 g was significantly higher than LE and LW at 22.61 g and 22.81 g, respectively. Across the three years within plots, HE and LW demonstrated no significant differences. HW recorded the lowest weight in 2016 at 21.89 g but increased significantly in 2017 and 2018 to 23.78 and 23.59 g, respectively.

Grain weight analysis over the three years revealed a consistent pattern, with the east side (HE and LE) significantly exceeding the west side (HW and LW) (Table 1). In 2016, HE and LE recorded weights of 4,245.7 and 4,349.9 kg ha^{-1}, while HW and LW recorded weights of 2,429.3 and 2,898.3 kg ha^{-1}, respectively. In 2017, HE and LE achieved weights of 5,089.0 and 4,973.4 kg ha^{-1}, surpassing HW and LW, which recorded weights of 3,131.1 and 3,552.7 kg ha^{-1}, respectively. Similarly, in 2018, HE at 4,622.0 kg ha^{-1} and LE at 5,759.0 kg ha^{-1} were significantly higher than HW and LW, which recorded weights of 2,542.7 and 2,691.6 kg ha^{-1}, respectively. Among the years within plots, no significant differences were observed in HE (range: 4,245.7 to 5,089.0 kg ha^{-1}), HW (range: 2,429.3 to 3,131.1 kg ha^{-1}), and LW (range: 2,691.6 to 3,552.7 kg ha^{-1}).

Harvest index in 2016 was higher in LE at 50.59% compared to HE at 45.48% or HW at 39.17% (Table 1, P<0.05). In 2017, harvest index showed no significant differences among plots, ranging from 42.28 to 46.54%. In 2018, HE at 51.58% was significantly higher than both LE and LW, at 45.24 and 37.65%, respectively (P<0.05).

Stem N uptake in 2016 was the highest in HE plots at 3.55 g N m^{-2}, while other fields ranged from 1.03 to 2.03 g N m^{-2} (Table 1). In 2017, HE and LW at 4.79 and 4.72 g N m^{-2},

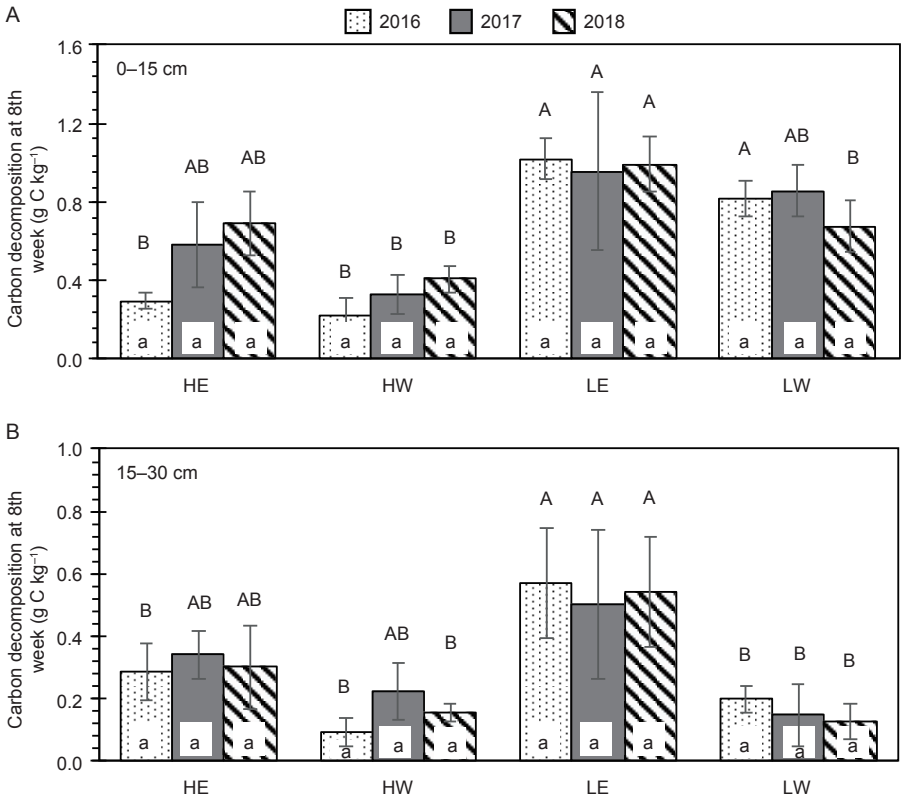


Fig. 3 Soil carbon decomposition at depths of 0–15 cm (A) and 15–30 cm (B) in reconstructed rice fields during the sampling period from 2016 to 2018. HE, high-elevation field east side; HW, high-elevation field west side; LE, low-elevation field east side; LW, low-elevation field west side. Values represent mean±standard deviation (n=3 for HE and HW, n=4 for LE and LW). Different uppercase letters denote significant differences among fields within the same year, while lowercase letters indicate significant differences among years within the same field, as determined by Tukey's HSD (P<0.05).

respectively, demonstrated the highest uptake compared to HW and LW at 1.18 and 1.82 g N m^{-2}, respectively. In 2018, LE exhibited the highest uptake at 5.00 g N m^{-2} among all fields. Across years, HE, HW, and LW showed no significant differences, ranging between 2.94–4.79, 1.00–1.28, and 1.03–1.82 g N m^{-2}, respectively.

Grain N uptake was consistently higher on the east side (HE and LE) compared to the west side (HW and LW) throughout the three consecutive years (Table 1). From 2016 to 2018, N uptake on the east side ranged from 4.47 to 7.10 g N m^{-2}, significantly exceeding that of the west side (2.11 to 2.96 g N m^{-2}). Among the three years, no significant variation was observed in HE, HW, and LW plots, while significant differences were detected in the LE plots.

4. Discussion

4.1. Effect of field reconstruction on SOC, TN, and their mineralization

Previous research has demonstrated that soil disturbance significantly affects SOC and TN (Grosse *et al.* 2011; Deng *et al.* 2013; Cheng *et al.* 2016; Takakai *et al.* 2020). In this study, the reconstruction impact on SOC and TN manifests under two conditions. First, the SOC and TN contents in the LE plots at subsurface soil layers exceeded those in the surface soil layers of the HE and HW plots. The elevated SOC and TN contents in the LE plots can be attributed to the relocation of surface soil layers from the LW plots, where former topsoil was removed from the west site. This removal resulted in LW plots having a reduced depth of fertile soil. Consequently, the second impact is that the LW plots demonstrated the lowest SOC and TN at the subsurface soil layers compared to other treatments. This condition differs from the HW plots, which maintain equivalent SOC and TN levels to the HE plots at a depth of 15–30 cm, despite losing topsoil during the landfilling process.

The addition of surface layers in the LE plots increased SOC by 4.1 and 37.6% in the surface and subsurface layers, respectively, compared to the LW plots in 2016. By 2018, the disparity between the LE and LW plots expanded to 14.1 and 81.7% in the surface and subsurface layers, respectively. This SOC increase in the LE plots resulted from its stability over time, while the LW plots experienced substantial decline. These findings align with previous research linking soil disturbance with SOC and TN. Bell *et al.* (2011) explained that substantial SOC losses can occur due to plowing or farming expansion, which alters the soil from its initial conditions. Eshaghi Rad *et al.* (2018) reported a decrease in SOC from 6.17% in less disturbed areas to 3.32 and 2.18% in moderately and severely disturbed areas, respectively. TN similarly decreased from 0.62% to 0.33% and 0.22% with moderate and severe disturbance levels.

This study reveals that reconstruction field activities alter C

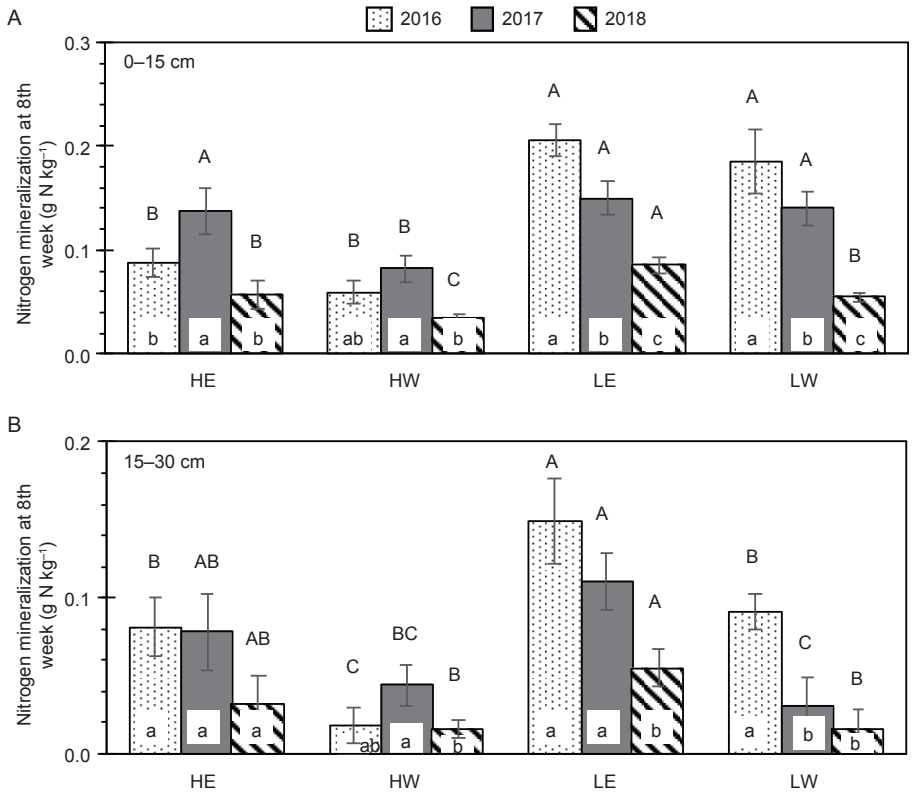


Fig. 4 Nitrogen mineralization at depths of 0–15 cm (A) and 15–30 cm (B) in reconstructed rice fields sampled from 2016 to 2018. HE, high-elevation field east side; HW, high-elevation field west side; LE, low-elevation field east side; LW, low-elevation field west side. Values represent mean±standard deviation (n=3 for HE and HW, n=4 for LE and LW). Different uppercase letters denote significant differences among fields within the same year, while lowercase letters indicate significant differences among years within the same field, as determined by Tukey's HSD (P<0.05).

Table 1 The effect of field reconstruction on rice yield components and N uptakes during the years 2016–2018[1)]

Year	Treatments[1)]	Panicle (number m^{-2})	1,000-grain weight (g)	Grain weight (kg ha^{-1})	Harvest index (%)	Stem N uptake (g N m^{-2})	Grain N uptake (g N m^{-2})
2016	HE	177.37±28.00 Aa	23.25±1.04 Aa	4,245.7±721.9 Aa	45.48±1.36 Bb	3.55±0.70 Aa	5.31±1.37 Aa
	HW	132.92±18.07 Ba	21.89±0.77 Ab	2,429.3±323.5 Ba	39.17±0.84 Cb	1.28±0.33 Ba	2.13±0.40 Ba
	LE	167.39±11.23 ABb	23.65±0.35 Aa	4,349.9±255.1 Ab	50.59±1.71 Aa	2.03±0.45 Bb	4.47±0.38 Ac
	LW	129.32±11.51 Bb	23.63±0.90 Aa	2,898.3±272.5 Ba	48.34±2.28 Aba	1.03±0.14 Ba	2.47±0.32 Ba
2017	HE	213.11±23.02 Ba	24.06±1.24 Aa	5,089.0±716.2 Aa	46.05±0.93 Ab	4.79±1.70 Aa	5.56±1.26 Aa
	HW	166.96±24.12 Ba	23.78±0.64 Aa	3,131.1±472.1 Ba	46.54±1.43 Aa	1.18±0.29 Ba	2.38±0.40 Ba
	LE	281.94±13.76 Aa	21.23±0.51 Bb	4,973.4±272.3 Ab	43.19±2.81 Ab	4.72±0.76 Aa	5.57±0.09 Ab
	LW	202.61±38.57 Ba	22.94±0.31 Aa	3,552.7±780.0 Ba	42.28±6.35 Aab	1.82±0.37 Ba	2.96±0.71 Ba
2018	HE	194.24±30.85 Ba	24.78±0.87 Aa	4,622.0±713.7 Aa	51.58±2.01 Aa	2.94±0.81 Ba	5.80±1.10 Aa
	HW	152.67±39.67 Ba	23.59±0.60 ABa	2,542.7±772.3 Ba	46.24±1.78 Aba	1.00±0.40 Ca	2.11±0.71 Ba
	LE	293.52±10.40 Aa	22.61±0.82 Ba	5,759.0±448.6 Aa	45.24±2.98 Bb	5.00±0.45 Aa	7.10±0.65 Aa
	LW	173.15±39.72 Bab	22.81±0.83 Ba	2,691.6±1084.3 Ba	37.65±2.85 Cb	1.77±0.62 BCa	2.35±0.99 Ba

[1)] HE, high field east side; HW, high field west side; LE, low field east side; LW, low field west side.
Values are presented as mean±standard deviation (n=3 for HE and HW, n=4 for LE and LW). Different uppercase letters denote significant differences among fields within the same years, while lowercase letters indicate significant differences among years within the same field according to Tukey's HSD (P<0.05).

decomposition and N mineralization in surface and subsurface layers. After five years of reconstruction, the LW plots exhibited reduced C decomposition and N mineralization compared to the LE plots, particularly in the surface soil layers (Appendix A; Figs. 3 and 4). Additionally, LW plots consistently demonstrated lower C decomposition values than LE plots across all observation years. This indicates that the LW plots, situated near the river, are significantly impacted by soil disturbance due to topsoil loss from the surface layers. The experiment demonstrates the strong influence of soil disturbance on C decomposition and N mineralization magnitude. These findings are corroborated by previous studies (Toriyama *et al.* 1988; Franzluebbers *et al.* 2000; Tanaka *et al.* 2012), which indicated that both C decomposition and N mineralization can be affected by different soil management practices. Soil disturbance disrupts soil aggregation, exposing previously

stable substrates to increased mineralization or decomposition of soil organic matter (Lado-Monserrat *et al.* 2014).

4.2. Effect of field reconstruction on rice yield components and N uptake

The three-year study results provide insights into how rice yield component changes relate to SOC, TN, and their mineralization, while also informing future land reconstruction decisions. These findings emphasize the significance of land reconstruction choices and their potential impact on rice yield within several years. Previous studies have established that soil quality significantly influences rice yield components (Mohanty *et al.* 2007; Siavoshi *et al.* 2011; Peng *et al.* 2017). Our results demonstrate similar conclusions, as illustrated in Figs. 3 and 4, and Table 1. The rice yield components after reconstruction showed substantial variations over the three years, primarily due to differences in SOC, TN, and their mineralization.

All rice yield components, except for 1,000-grain weight, exhibited significant correlations with various soil parameters in both surface and subsurface soil layers (Table 2). SOC, TN, and C decomposition at the depth of 0–15 cm played a fundamental role in determining panicle number. Notably, panicle number correlated with TN (R=0.362, P<0.05) and C decomposition (R=0.556, P<0.01) in the 15–30 cm soil layer. This observation aligns with previous research by Peng *et al.* (2017), which demonstrated that improving SOC could substantially enhance panicle number. Furthermore, the current study revealed that grain weight correlated significantly (P<0.01) with all selected soil parameters in the two soil layers, except for N mineralization at 0–15 cm depth. Lal (2020) established that enhancing soil quality and health through increased SOC positively influences crop yield. A meta-analysis by Oldfield *et al.* (2019) demonstrated that increasing SOC can enhance potential yields in maize and wheat by 10 and 23%, respectively.

The harvest index indicates the plant's capacity to distribute metabolic products to reproductive parts, such as grains in rice crops. In this study, N mineralization in both layers correlated with the harvest index (Table 2). Moreover, SOC, TN, C decomposition, and N mineralization in subsurface soil layers exhibited significant correlations (P<0.05 or 0.01) with the harvest index, with R values of 0.321, 0.369, 0.384, and 0.421, respectively. In the surface soil layers, C decomposition, along with SOC and TN in the subsurface layers, significantly correlated with stem N uptake. Additionally, grain N uptake correlated with SOC (R=0.340, P<0.05) and C decomposition (R=0.383, P<0.05) in the surface soil layers, as well as with all soil properties in the subsurface soil layers. These findings suggest that rice yield was closely linked to soil properties in both surface and subsurface soil layers following land reconstruction.

Variations in rice yield and its components are influenced by soil properties and fertilization, as well as meteorological factors including temperature, precipitation, and irrigation during the rice growing season. Although meteorological data collection at the research site was not feasible, future studies should address this limitation. Nevertheless, the results of this study provide a substantial foundation for evaluating land reconstruction practices in maintaining sustainable rice yields in Japan.

5. Conclusion

Changes in soil quality resulting from anthropogenic disturbances during field reconstruction are inevitable. The consequent effects, particularly the reduction in crop yields, require significant attention due to their direct impact on agricultural production. Despite some uncertainties regarding rice yield components over the three-year observation period, this study emphasizes the fundamental role of soil quality in land reconstruction decisions. The findings indicate that monitoring soil properties — such as SOC, TN, C decomposition and N mineralization — before and after field reconstruction is crucial for identifying and mitigating potential yield losses associated with declining soil quality. This recommendation extends to organic rice farmers, conventional farmers, and agricultural policymakers.

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Table 2 The value of correlations between soil properties and rice yield components or N uptakes

Depth (cm)	Soil properties	Panicle number	1,000-grain weight	Grain weight	Harvest index	Stem N uptake	Grain N uptake
0–15	Soil organic carbon	**0.354***	–0.216	**0.393***	0.217	0.257	**0.340***
	Total nitrogen	**0.392***	–0.205	**0.385***	0.157	0.280	**0.336***
	C decomposition	**0.461****	–0.091	**0.446****	0.120	**0.363***	**0.383***
	N mineralization	0.034	–0.059	0.236	**0.316***	0.087	0.128
15–30	Soil organic carbon	0.235	–0.105	**0.425****	**0.321***	**0.399****	**0.491****
	Total nitrogen	**0.362***	–0.121	**0.551****	**0.369***	**0.501****	**0.609****
	C decomposition	**0.556****	–0.104	**0.712****	**0.384***	**0.551****	**0.697****
	N mineralization	0.171	–0.050	**0.431****	**0.423****	0.297	**0.389***

The bold number indicates a statistically significant correlation (n=42). * and ** indicate significance at P<0.05 and P<0.01, respectively.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that they did not use AI in the preparation and writing of this manuscript.

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