Spanish Journal of Agricultural Research
22 (1), e1101, 9 pages (2024)
eISSN: 2171-9292
https://doi.org/10.5424/sjar/2024221-19824
INIA-CSIC

RESEARCH ARTICLE

OPEN ACCESS

Land leveling and cover cropping impacts on chemical and biological properties of paddy soil

Masoumeh Izadpanah[1], Mahmoud Shabanpour[1], Sepideh Abrishamkesh[1*] and Iraj Bagheri[2]

[1] *Department of Soil Science and Engineering, Faculty of Agricultural Science, University of Guilan, Rasht, Iran.*
[2] *Department of Biosystem Engineering, Faculty of Agricultural Science, University of Guilan, Rasht, Iran.*

***Correspondence** should be addressed to Sepideh Abrishamkesh: sabrishamkesh@guilan.ac.ir

Abstract

Aim of study: To examine the impact of solitary land leveling and its combination with cover cropping on the chemical and biological characteristics of paddy soil.

Area of study: This research focused on paddy fields located in Guilan Province, situated in northern Iran. Specifically, two sites were chosen for investigation, where land leveling had been conducted 5 years and 2 years prior to this study, respectively. Furthermore, cover cropping was implemented during the second year after the latter area's land leveling.

Material and methods: A total of 80 composite soil samples were collected, with 20 samples gathered from both leveled and unleveled plots at the designated study sites. Various soil chemical and biological properties such as organic carbon, total nitrogen, available phosphorus, exchangeable potassium, microbial respiration, and biomass carbon were quantified. Subsequently, a paired t-test was employed to analyze the impact of land leveling and the combined effects of land leveling with cover cropping on soil attributes.

Main results: The study revealed that five years after land leveling, there was a significant decrease in organic carbon, total nitrogen, microbial respiration, and biomass carbon. In contrast, the area leveled and cover cropped for two years exhibited higher levels of these attributes compared to adjacent unleveled parcels.

Research highlights: This study highlights the distinct effects that solitary land leveling and land leveling combined with sustainable practices like cover cropping have on soil attributes.

Additional key words: land consolidation; metabolic quotient; soil removal; soil management.

Abbreviations used: EC (electrical conductivity); L_2 (land leveling had been executed 2 years prior); L_5 (land leveling had been executed 5 years prior); OC (organic carbon); q_{mic} (microbial quotient); q_{CO2} (metabolic quotient); SOC (soil organic carbon); U_2, U_5 (unleveled paddy fields as control sites for L_2 and L_5).

Citation: Izadpanah, M; Shabanpour, M; Abrishamkesh S; Bagheri, I (2024). Land leveling and cover cropping impacts on chemical and biological properties of paddy soil. Spanish Journal of Agricultural Research, Volume 22, Issue 1, e1101. https://doi.org/10.5424/sjar/2024221-19824

Received: 13 Sep 2022. **Accepted**: 06 Nov 2023. **Published**: 06 Feb 2024.

Introduction

Asia grows almost 90% of the world's rice (*Oryza sativa* L) (GRiSP, 2013), mostly on small plots of land with a high labor-intensive input ratio (Balasubramanian, 2018). Consolidating these divided areas can increase farm output and mechanization (Nguyen & Warr, 2020). Land consolidation, sometimes referred to as land leveling, is the process of combining disparate parcels into cohesive areas in order to maximize the use of land in places that have been negatively impacted by natural catastrophes, production, manufacturing, inefficiency, or neglect (Liu et al., 2019). This practice improves irrigation management and facilitates agricultural mechanization. Moreover, it reduces water consumption, promoting the conservation of water resources (Parfitt et al., 2014). However, it is essential to note that land consolidation can have both positive and negative impacts on ecosystems' ecological services, requiring attention and regulatory measures (Firbank et al., 2013). For instance, land leveling significantly disturbs the soil, altering the equilibrium of the near-surface soil environment (Oztekin et al., 2013). Various authors have examined the effects of land leveling on soil attributes. Dioni et al. (2016) investigated its impacts in a rice-soybean rotation in Capital de Leo Rio Grande Sul, Brazil, finding that both bulk density and organic matter showed higher sensitivity to land leveling operations. Similarly, Zhang et al. (2016) studied land consolidation over time on soil properties in Shanxi, China. They noted fluctuations in soil nutrient levels during reclamation periods of less than 3 years, with increases observed after 3 or 4 years. Parfitt et al. (2013) indicated that land leveling can negatively impact surface soil fertility, leading to decreased soil organic carbon (SOC), cation exchange capacity, total nitrogen (N), phosphorus (P), calcium, sulfur, iron, zinc, and manganese. Additionally, Brye et al. (2003) examined changes in soil physical and biological properties following land leveling in eastern Arkansas, USA. They reported a significant decrease in fungal populations and bacterial biomass.

These days, land leveling is extensively used throughout the world, albeit with diverse approaches across different countries. The formal introduction of land leveling in Iran traces back to the late 1980s and has experienced substantial acceleration in recent decades. In Guilan, the northern province of Iran, more than 76,000 hectares of paddy fields have undergone consolidation, with plans for continued expansion in line with the government's agricultural policies. The satisfaction of farmers involved in these projects is contingent upon several factors such as economic efficiency, working conditions, technical effectiveness, and soil productivity (Allahyari et al., 2018). To ensure well-informed planning and execution of land leveling operations, as well as to prioritize soil management, it is crucial to assess and monitor the impacts of land leveling on soil quality.

Previous studies have predominantly focused on investigating the effects of only land leveling on soil, with limited research dedicated to exploring integrated technologies. Remarkably, there have been no comprehensive efforts to examine the combined impact of land leveling and cover cropping on soil. Cover cropping, involving the cultivation of closely spaced crops to protect soil, seeds, and enhance soil quality during typical crop production intervals (Quintarelli et al., 2022), remains relatively unexplored in the current literature. Thus, this study aimed to explore the chemical and biological properties of two paddy soils that underwent land leveling operations. Furthermore, it sought to evaluate the effectiveness of cover cropping in achieving favorable outcomes for land leveling. Our hypothesis posited that combining cover crops with land leveling would significantly influence soil chemical and biological attributes, contributing to the success of land leveling in paddy lands. The anticipated findings of this research are expected to provide valuable insights into the consequences of land leveling and delineate essential soil management practices for leveled soils in the future.

Material and methods

Site description

This research was conducted within Rasht County, Guilan Province, Iran, spanning an area between Limochah (49°48'36.54"E - 37°19'49.54"N) and Bala Mahalleh-ye Gafsheh (49°48'36.99"E - 37°20'7.56"N) (Fig. 1a,b). The mean annual precipitation in this region totals approximately 1,359 mm. The soil in this area falls under the Aquept suborder, characterized predominantly by clay and silty clay loam textures.

Two specific sites (Fig. 1c) were selected for the study, representing land leveling activities that occurred 2 and 5 years prior to the study (L_2 and L_5, respectively). Additionally, adjacent unleveled (traditional) paddy fields were chosen as control sites (U_2 and U_5, respectively). In L_2, clover served as a cover crop (green manure) during the last growing season. Four leveled and four unleveled parcels were selected within the two aforementioned study sites considering soil type, rice varieties, soil management practices, microclimate conditions, etc.

Soil sampling

Immediately following the rice harvest, five composite soil samples were systematically collected in August 2018 from the surface layer (0-20 cm) of each of the 16 parcels using a randomized sampling design. This process yielded a total of 80 soil samples, which were then transported to the laboratory. A portion of these samples underwent air-drying and sieving through 2 mm screens for the assessment of chemical properties, including pH, electrical conductivity (EC), available P, and potassium (K). Another subsample was ground through a 0.5 mm-mesh sieve for the determination of organic carbon (OC) and N. Furthermore, a separate set of samples was specifically preserved for subsequent biological analyses and stored refrigerated at 4°C.

Soil chemical and biological analysis

Chemical attributes

Various standard methods were employed to assess soil pH and EC in saturated paste extracts using a pH meter and EC meter, respectively. SOC and N were determined via the Walkley & Black (Nelson & Sommers, 1982) and Kjeldahl (Bremner & Mulvaney, 1982) wet oxidation procedures, respectively. Available K levels were evaluated using the acetate ammonium extraction method (Knudsen et al., 1982) and quantified through a flame photometer. Available P content was determined by the Olsen method

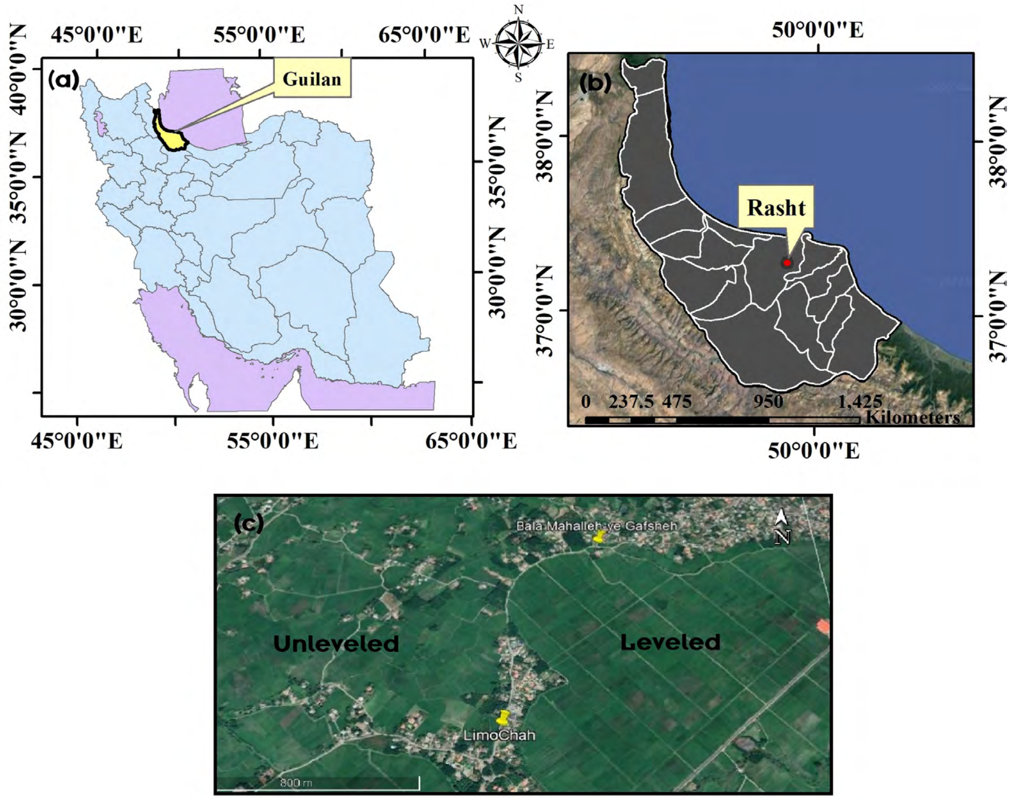

Figure 1. Location of the study areas (a, b). An overview of land leveling in the study area (c).

(Olsen & Sommers, 1982) employing a spectrometer for measurement.

Biological attributes

Soil biological attributes, including microbial respiration and microbial carbon biomass, were evaluated using specific methods. For microbial respiration assessment, 20 g of each soil sample (on an oven-dry basis) were taken and preconditioned to reach 60% of their water holding capacity. These prepared samples were then placed in 1-L stoppered glass jars. The CO_2 emitted during a 10-day incubation period was absorbed in 2 mL of 1 M NaOH. The excess NaOH was titrated with 0.1 M HCl to quantify the evolved CO_2 (Badalucco et al., 1992). The calculated CO_2 value within a 24-hour period was multiplied by a factor of 0.27 to convert it into the corresponding amount of carbon, representing microbial respiration.

To determine microbial carbon biomass using the fumigation extraction method (Vance et al., 1987), soil moisture was adjusted to 50% of field capacity. Each sample was divided into two subsamples. One subsample remained non-fumigated, while the other (25 g dry weight) was fumigated with chloroform ($CHCl_3$) for 24 hours at a temperature of 25°C (Jenkinson & Powlson, 1976). After removing the $CHCl_3$, carbon was extracted from both fumigated and non-fumigated subsamples using 0.5 M K_2SO_4. The OC in the filtered extracts was quantified using the wet oxidation method. The difference between the carbon extracted from fumigated and non-fumigated subsamples (E_C) was then converted into microbial biomass carbon (MBC, mg kg^{-1}) using the following equation:

$$MBC = \frac{E_C}{k_{EC}} \qquad (1)$$

where k_{EC} is the conversion factor used to transform chloroform labile carbon into microbial carbon biomass.

Biological indexes

Soil biological indexes, including metabolic (q_{CO2}) and microbial (q_{mic}) quotients, were calculated; q_{CO2} is defined as the amount of $C\text{-}_{CO2}$ produced per unit of soil microbial biomass per unit of time (Anderson & Domsch, 1993); meanwhile, q_{mic} is the ratio between microbial biomass carbon and SOC (Powlson et al., 1997).

Statistical analyses

All data underwent descriptive statistical analysis and were assessed for normality using the non-parametric Kolmogorov-Smirnov test at a significance level of 5%. Paired t-tests were performed at probability levels of 0.1%, 1%, and 5% using SPSS version 8.2 to determine the overall impact of land leveling and the combined effects of land leveling and cover cropping on the datasets.

The relative change in the studied properties of leveled soils compared to unleveled ones (RCX_i) was calculated as a percentage using Eq. (2). Here, X_B and X_C represent the values of each studied parameter in the leveled and unleveled soils, respectively.

$$RCX_i(\%) = \frac{(X_B - X_C)}{X_C} \qquad (2)$$

Results

Impact of land leveling on soil chemical and biological properties

The findings of this study revealed notable differences in various soil chemical and biological parameters between soils that underwent leveling for five years (L_5) and the adjacent unleveled lands (U_5).

Following five years of land leveling, the soil pH in L_5 exhibited a substantial increase ($p<0.01$) compared to U_5, suggesting a shift towards a more alkaline environment. In contrast, soil EC showed a significant decrease ($p<0.01$) in L_5 when compared to U_5 (Table 1).

The levels of OC and N in the soil notably decreased ($p<0.01$) due to the five-year land leveling, indicating potential changes in SOC content and nutrient availability.

The available concentration of P was notably lower ($p<0.01$) in L_5 compared to U_5, suggesting a potential decline in the availability of this crucial nutrient. Conversely, the exchangeable K content exhibited a significant increase ($p<0.01$) in L_5 compared to U_5, implying potential enhancements in the availability of this nutrient (Table 1).

Biological parameter assessment indicated that L_5 displayed significantly lower microbial respiration and biomass carbon ($p<0.01$) in comparison to U_5 (Fig. 2). This suggests a potential reduction in soil microbial activity and carbon storage subsequent to the land leveling process. Moreover, the biological indexes of q_{mic} and q_{CO2} were notably higher ($p<0.05$) in L_5 than in U_5 (Table 2).

Analyzing the changes in soil chemical characteristics brought about by the land leveling over a 5-year period (Fig. 3) showed a little rise in soil pH of 2.72%. On the other hand, there was a noticeable decrease in the soil's EC, OC, N, and available P, with values ranging from 12.2% to 49.6%. Exchangeable K, in particular, showed a significant rise with a value of 47.62% (Fig. 3).

Effect of land leveling and cover cropping on soil chemical and biological properties

The results revealed significant alterations in various soil chemical and biological parameters in soils subjected to two years of land leveling and cover cropping (L_2) compared to adjacent unleveled lands (U_2).

After two years of land leveling and cover cropping, the soil pH in L_2 exhibited a notable decrease ($p<0.01$) compared to U_2, indicating a shift towards increased acidity. Conversely, soil EC displayed a significant increase ($p<0.05$) in L_2 compared to U_2. This rise in EC contrasted with the observed alteration in soil pH (Table 1).

The combination of two-year land leveling and cover cropping led to a substantial increase ($p<0.01$) in OC and N in the soil (Table 1). However, the available P concentration was notably lower ($p<0.01$) in L_2 compared to U_2, suggest-

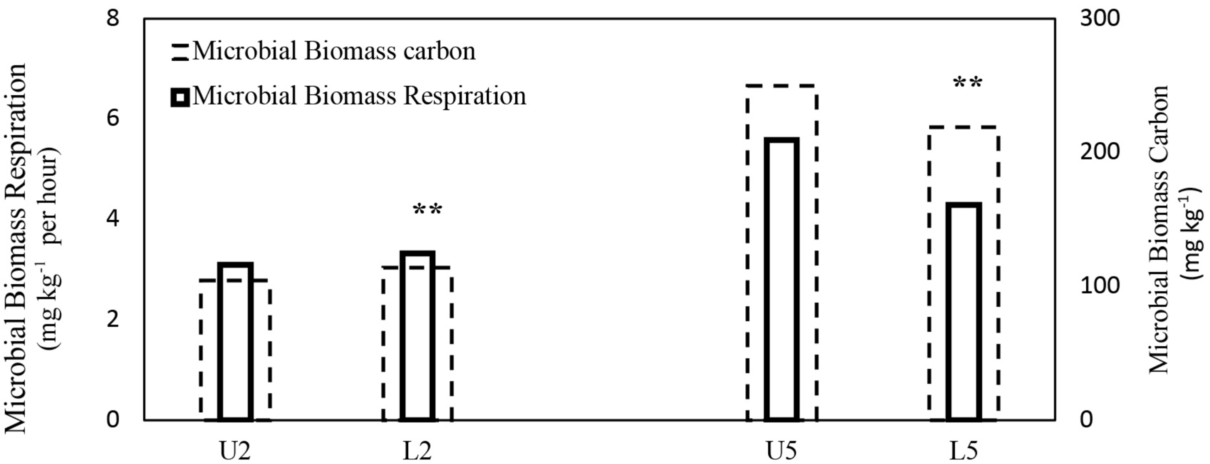

Figure 2. Soil biological attributes of unleveled and leveled lands. L_5: five-year leveled land, U_5: adjucent unleveled lands to five-year leveled lands, L_2: two-year leveled and cover croped land, U_2: adjucent unleveled lands to two-year leveled and cover croped lands. **Significant by the t test, at 1% probability applied to mean values (n=20) of each attribute in unleveled and leveled soil.

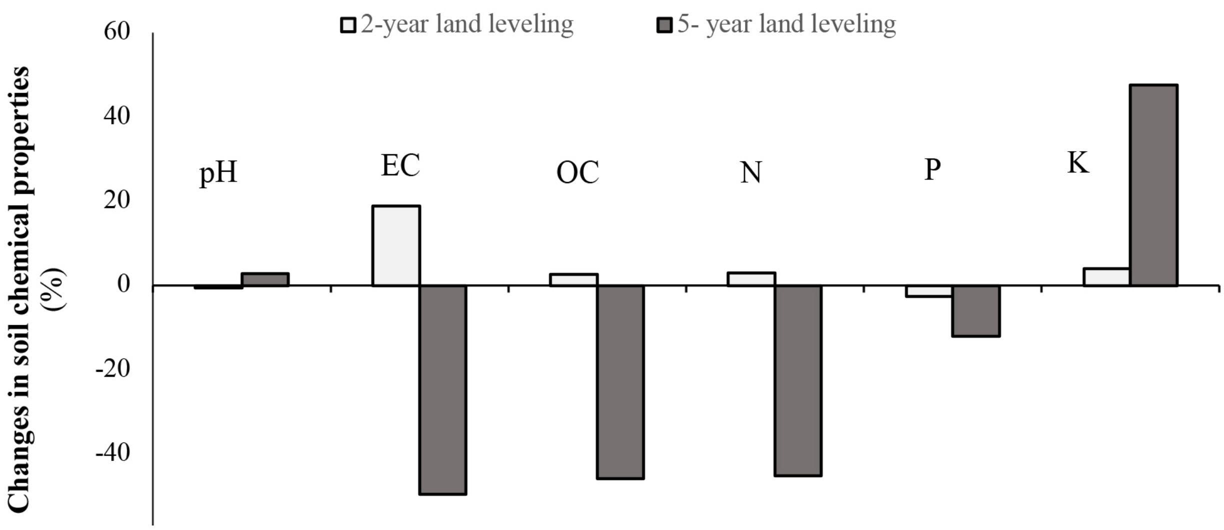

Figure 3. Changes in the percentage of soil chemical attributes: EC, electrical conductivity; OC, organic carbon content; N, total nitrogen; P, available phosphorus; K, exchangeable potassium.

ing a potential decrease in the availability of this essential nutrient. On the other hand, the content of exchangeable K showed a significant increase ($p<0.01$) in L_2 compared to U_2, implying potential enhancements in its availability (Table 1).

A slight decrease in soil pH and available P was found when the 2-year land leveling was analyzed to examine the changes in soil chemical characteristics. Conversely, there was a slight rise in SOC, N, and exchangeable K, ranging from 2.56% to 3.97%. The value of 18.8% for soil EC in particular showed a notable rise (Fig. 3).

According to the biological parameter analysis, L_2 significantly outperformed U_2 in terms of biomass carbon and microbial respiration ($p<0.01$) (Fig. 2). This suggests that the combined effects of cover crops and land leveling have increased soil microbial activity and carbon storage. On the other hand, soils that were leveled and covered with cover crops for a period of two years did not exhibit a significant effect on q_{mic} and q_{CO2} from L_2 (Table 2).

Discussion

Soil chemical properties

A key area of research in soil science is soil chemistry, which has a big impact on soil productivity, capacity for self-purification, and nutrient balance (Renkou et al., 2020). Our study clarifies the impact of cover crops and land leveling on the chemical characteristics of soil.

Soil pH and electrical conductivity (EC)

Soil pH, a critical measure of soil acidity or alkalinity, plays a pivotal role in determining overall soil health and productivity. Our findings demonstrate subtle changes in soil pH at L_2 and L_5, potentially affecting nutrient availability

Table 1. Soil chemical attributes of unleveled and leveled lands.

	pH	EC (dS m^{-1})	OC (g kg^{-1})	N (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})
L_5	7.17**	0.63**	9.9**	1. 7**	58**	186.3**
U_5	6.98	1.27	18.3	3. 1	66	126.2
L_2	7.55**	2.91*	19.8**	3.4**	38**	442.9**
U_2	7.59	2.45	19.3	3.3	39	426

L_5: five-year leveled land, U_5: adjucent unleveled lands to five-year leveled lands. L_2: two–year leveled and cover croped land. U_2: adjucent unleveled lands to two-year leveled and cover cropeed lands. EC: electrical conductivity. OC: organic carbon content. N: total nitrogen. P: available phosphorus. K: exchangeable potassium. *,**: significant by the t test, at 5 and 1 probability, respectively, applied to mean values (n=20) of each attribute in unleveled and leveled soil.

Table 2. Soil biological parameters of unleveled and leveled lands.

	q_{CO2} (g kg^{-1} h^{-1})	q_{mic} (%)
L_5	36.23*	1.63*
U_5	31.85	1.14
L_2	24.41^ns	0.62^ns
U_2	24.02	0.60

L_5, U_5, L_2, U_2: see Table 1. q_{CO2}: metabolic quotient (g kg^{-1} h^{-1}). q_{mic}: microbial quotient (%). ns: non-significant. *: significant by the t test, at 5% probability applied to mean values (n=20) of each index in unleveled and leveled soil.

and crop uptake. We observed an increase in soil pH and a decrease in EC after five years of leveling (L_5), consistent with observations made by Oztekin et al. (2013). In contrast, Sharifi et al. (2014) observed a decrease in soil pH concurrent with an increase in EC after a four-year period of land leveling, which aligns with the trends found in our study concerning soil pH following a two-year period of leveling combined with cover cropping (L_2). Interestingly, Parfitt et al. (2013) reported no changes in soil pH after a three-month land leveling process. The exposure of subsoil to the surface subsequent to land leveling may induce significant pH variations (Robbins et al., 1997). Consistent with our findings from the combination of land leveling and cover cropping, Lin et al. (2022) observed the highest average soil pH in non-agricultural land consolidation areas. Additionally, in consolidated areas where activities such as constructing ditches, merging plots, employing organic fertilizers, and implementing comprehensive enhancements were carried out, soil pH tended to approach neutrality. This implies that the use of organic fertilizers can diminish reliance on inorganic alternatives, aiding in effective regulation of soil pH levels.

The alteration in soil pH observed in both the leveled (L_5) and the leveled and cover cropped soils (L_2) in this study was relatively modest, showing a marginal decrease of 0.04 units in L_2 and an increase of 0.19 units in L_5 (Table 1 and Fig. 3). These slight fluctuations may have limited implications on crop yield, especially when considering the dynamic nature of soil systems and the inherent buffering capacity of agricultural soil.

Soil organic carbon (SOC)

The impact of five-year land leveling resulted in a significant reduction in SOC content, whereas the combination of two-year land leveling with cover cropping showed an increase (Table 1). Specifically, the prolonged five-year land leveling practice led to a noticeable depletion of SOC, whereas the combined approach of land leveling and cover cropping indicated a tendency to enhance SOC storage. This transformation is evident in the alteration of SOC content, with L_5 experiencing a decline of approximately 45.9%, while L_2 showcased a modest increase of 2.6% (Fig. 3).

The documented decrease in SOC attributed to land leveling aligns with earlier research findings (e.g. Brye et al., 2004; Parfitt et al., 2013; Sharifi et al., 2014; Li et al., 2018). Notably, SOC plays a crucial role in influencing crop growth. Consequently, the decline of SOC in L_5 indicates a significant reduction in the soil's capacity for crop production and exacerbates the issue of global warming (Li et al., 2018). The disturbance and removal of the soil surface during intensive land leveling practices significantly affect SOC dynamics. The installation of drainage systems and subsequent improvement of soil aeration can accelerate the decomposition of OC. Shepherd et al. (2001) reported an increase in microbial decomposition of soil organic matter due to land leveling. Moreover, the disruption of soil aggregates can amplify the decomposition and mineralization of OC, as emphasized by Sharifi et al. (2014). On the contrary, the combined practices of land leveling and cover cropping (L_2) resulted in an increase in SOC content, indicating a potential improvement in both SOC levels and nutrient availability. However, the overall change in SOC was relatively modest at +2.6%. This aligns with previous research by Nascente & Crusciol (2015), which highlighted the positive impact of cover crops on enhancing SOC content. The integration and widespread adoption of cover crops in agricultural systems enhance soil characteristics through various mechanisms. These include the establishment of diversified root systems that alleviate soil compaction, the absorption and cycling of nutrients from deeper soil layers, and the promotion of rhizosphere interactions that enhance nutrient allocation within the organic fraction of the soil (Arai et al., 2018).

Total nitrogen, available phosphorus, and exchangeable potassium

The alterations in N in L_5 and L_2 sites closely mirrored the observed pattern in SOC content. It is important to note that approximately 95% of soil N consists of organic N. Hence, the fluctuations in N within this study can be readily understood through changes in SOC content. A significant decrease in N was evident at L_5, while an increase was observed at L_2.

Utilizing cover crops as green manure presents an effective method to augment nutrients within a cropping system. Furthermore, leguminous cover crops offer an added advantage by enhancing soil fertility through biological N fixation. This process involves the conversion of atmospheric dinitrogen gas (N_2) into plant-accessible ammonium (NH_4^+) within legume root nodules, facilitated by symbiotic interactions with nitrogen-fixing rhizobia bacteria (Parr et al., 2011).

Our investigation revealed a significant decrease in the availability of P and a corresponding increase in exchangeable K within L_5 and L_2 when compared to their unleveled counterparts (Table 1). The reduction in available P was recorded at 2.6% for L_2 and a more notable 12.12% for L_5

(Fig. 3). Particularly, the decline in available P was more pronounced in L_5 compared to L_2 (Fig. 3), a trend that could potentially be attributed to the comparatively lower OC content found in leveled soils in L_5. Mohebbi (2014) previously reported a positive correlation between P and organic matter. Unlike K, which can be leached from the surface and accumulate in lower soil profiles, the mineralization of organic components contributes partially to fulfilling plant P requirements. The decrease in available P in leveled soils can also be linked to the lower P content observed in the exposed subsoil (Sharifi et al., 2014).

Our findings of reduced available P after land leveling are consistent with prior research (e.g., Brye et al., 2004; Parfitt et al., 2013; Sharifi et al., 2014). Conversely, the slight decrease in available P within L_2 can also be attributed to the introduction of cover crops. These crops can act as "catch crops," retrieving less available nutrients from deeper soil horizons and enhancing fertility in the rhizosphere. Specifically, the uptake of P by cover crops can result in its release into shallower soil horizons following the decomposition of plant residues and mineralization within the microbial immobilized pool (Alamgir et al., 2012).

In both L_5 and L_2, there was a notable increase in exchangeable K compared to adjacent unleveled soils (Table 1). The alteration in the percentage of exchangeable K was more prominent in L_5 than in L_2 (Fig. 3). The detected rise in exchangeable K after land leveling is consistent with findings from studies by Brye et al. (2004) and Parfitt et al. (2013).

In the study conducted by Parfitt et al. (2013), it was noted that the average K content deviated from anticipated levels, showing an increase subsequent to land leveling. This rise is attributed to the higher presence of K in the soil resulting from the application of inorganic K fertilizers. As K is a mobile cation in soil, it was expected to leach from the surface and accumulate in the subsoil (Parfitt et al., 2013). The presence of clay minerals, particularly illite, in the subsurface horizon of argillic soils, may also contribute to enhancing the exchangeable K in leveled soils (Brye et al., 2004). However, Sharifi et al. (2014) reported a notable decrease in exchangeable K subsequent to land leveling, without identifying the specific cause for this decline.

Soil biological properties

Our findings emphasize that the five-year land leveling (L_5) resulted in a significant decrease in both microbial respiration and biomass carbon (C) compared to unleveled soils. This decline is likely due to the decrease in OC and N content. Previous research has shown that microbial biomass C decreases when soil C and N are reduced following land leveling activities (Sharifi et al., 2014). The observed drop in microbial respiration could also be linked to inadequate leveling practices, excavation procedures in leveled areas, and the absence of proper soil management protocols. Land leveling interventions have the potential to disrupt the nutrient cycle balance, resulting in reduced native bacterial populations, increased ecological risks, altered biodiversity, and shifts in microbial populations (Yu et al., 2010). In contrast, the combination of land leveling with cover cropping (L_2) led to increased microbial respiration and biomass C. This elevation might be attributed to the release of essential plant nutrients from organic matter, which acts as a primary driver for enhanced respiration. Studies have indicated that the addition of plant residues to soil elevates microbial biomass C (Zhang et al., 2010). There is a recognized positive correlation between SOC and microbial biomass C, indicating their close relationship (Xue & Huang, 2013). Parfitt et al. (2013) also reported an increase in microbial C biomass following land leveling, attributing it to the severe disturbance of the soil due to the breakdown of larger aggregates during the leveling operation. The introduction of cover cropping in the two-year leveled lands likely contributed to enhanced soil organic matter content and provided favorable aeration conditions conducive to microbial growth and activity. Despite the adverse impacts of land leveling on soil biological properties evident in the five-year land leveling areas, the introduction of cover cropping emerges as a crucial factor for the slight yet significant increase in microbial respiration and biomass C observed in L_2.

The microbial quotient (q_{mic}), which measures the amount of C-CO_2 produced per unit of soil microbial biomass over a specific time, provides insights into microbial activity and its potential impact on organic matter breakdown in the soil (Feketeova et al., 2021). Our findings indicate that the five-year land leveling intervention led to a 45% reduction in SOC (Fig. 3) and a 23% decrease in microbial C biomass (Fig. 2). As a result, a more substantial decrease in OC compared to microbial C biomass significantly raised the q_{mic} in the five-year leveled soils. The metabolic quotient (q_{CO2}), a ratio between microbial biomass C and SOC, serves as an indicator of microbial stress; higher values suggest unfavorable conditions for microbial growth (Xue & Huang, 2013). An elevation in q_{CO2} was noted following a five-year land leveling process, contrasting with the absence of significant changes observed in areas where a two-year land leveling procedure was combined with cover cropping. The observed increase in q_{CO2} within the L_5 context could potentially be linked to ecological disturbances resulting from land leveling practices, coinciding with reductions in SOC and fertility parameters such as N and available P.

Conclusion

This study investigated the impacts of solitary land leveling as well as land leveling coupled with cover cropping on soil chemical and biological characteristics. Our findings highlight the intricate effects of land leveling on attributes of paddy soil. Over a span of five years, solitary land leveling resulted in a reduction in soil organic carbon, total nitrogen, and microbial activity. Conversely, combining two-year land leveling with cover cropping exhibited positive effects on organic carbon, total nitrogen, and microbial activity. Nonetheless, there was a decrease in exchangeable K levels in both scenarios of land leveling, while available phosphorus content showed contrasting trends. Overall, our results suggest that implementing sustainable soil management practices, particularly cover cropping, can mitigate potential negative impacts of land leveling. This underscores the significance of strategic approaches to uphold soil health and productivity in paddy fields.

Data availability: Not applicable.

Competing interests: The authors have declared that no competing interests exist.

Authors' contributions: **Masoumeh Izadpanah:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Visualization, Writing – original draft. **Mahmoud Shabanpour**: Conceptualization, Methodology, Project administration, Resources, Software, Visualization, Writing – review & editing. **Sepideh Abrishamkesh:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Writing – review & editing. **Iraj Bagheri:** Conceptualization, Methodology, Validation, Writing – review & editing.

Funding: The authors received no specific funding for this work.

References

Alamgir MD, McNeill A, Tang C, Marschner P, 2012. Changes in soil P pools during legume residue decomposition. Soil Biol Biochem 49: 70-77. https://doi.org/10.1016/j.soilbio.2012.01.031

Allahyari MS, Damalas CH, Daghighi Masouleh Z, 2018. Land consolidation success in paddy fields of northern Iran: An assessment based on farmers' satisfaction. Land Use Policy 73: 95-101. https://doi.org/10.1016/j.landusepol.2018.01.035

Anderson TH, Domsch KH, 1993. The metabolic quotient for CO2 (qCO2) as a specific activity parameter to assess the effects of environmental conditions, such as pH, on the microbial biomass of forest soils. Soil Biol Biochem 25: 393-395. https://doi.org/10.1016/0038-0717(93)90140-7

Arai M, Miura T, Tsuzura H, Minamiya Y, Kaneko N, 2018. Two-year responses of earthworm abundance, soil aggregates, and soil carbon to no-tillage and fertilization. Geoderma 332: 135-141. https://doi.org/10.1016/j.geoderma.2017.10.021

Badalucco L, Grego S, Dell'Orco S, Nannipieri P, 1992, Effect of liming on some chemical, biochemical and microbiological properties of acid soil under spruce (*Picea abies* L.). Biol Fert Soils 14: 76-83. https://doi.org/10.1007/BF00336254

Balasubramanian V, 2018. Future of smallholder rice farming in Asia: emerging issues, challenges, and opportunities. Rice-Based Biosyst 4: 1-17.

Bremner JM, Mulvaney CS, 1982. Nitrogen-Total. In: Methods of soil analysis. Part 2. Chemical and microbiological properties; Page AL, et al. (Eds.), American Society of Agronomy, SSSA Book Series, Madison, WI, USA, pp: 595-624. https://doi.org/10.2134/agronmonogr9.2.2ed.c31

Brye KR, Slaton NA, Mozaffar M, Savin MC, Norman RJ, Miller DM, 2004. Short-term effects of land consolidation on soil chemical properties and their relationships with microbial biomass. Soil Sci Soc Am J 68: 924-934. https://doi.org/10.2136/sssaj2004.9240

Brye KR, Slaton NA, Stavin MC, Norman RJ, Miller DM, 2003. Short-term effects of land consolidation on soil physical properties and microbial biomass. Soil Sci Soc Am J 67: 1405-1417. https://doi.org/10.2136/sssaj2003.1405

Dioni GBB, Willian SB, Luis CT, Dongli S, Letiane HP, Jose MBP, et al., 2016. Multivariate and geostatistical analyses to evaluate lowland soil levelling effects on physico-chemical properties. Soil Till Res 156: 63-73. https://doi.org/10.1016/j.still.2015.10.004

Feketeova Z, Hrabovsky A, Simkovic I, 2021. Microbial features indicating the recovery of soil ecosystem strongly affected by mining and ore processing. Int J Environ Res Public Health 18: 3240. https://doi.org/10.3390/ijerph18063240

Firbank L, Bradbury RB, McCracken DI, Stoate C, 2013. Delivering multiple ecosystem services from enclosed farmland in the UK. Agric Ecosyst Environ 166: 65-75. https://doi.org/10.1016/j.agee.2011.11.014

GRiSP, 2013. Rice almanac., 4th ed. Global Rice Science Partnership. Los Baños, Philippines International Rice Research Institute, pp: 283.

Jenkinson DS, Powlson DS, 1976, The effects of biocidal treatments on metabolism in soil A method for measuring soil biomass. Soil Biol Biochem 8: 209-213. https://doi.org/10.1016/0038-0717(76)90005-5

Knudsen D, Peterson GA, Pratt PF, 1982. Lithium, sodium and potassium. In: Page AL et al. (eds.). Methods of Soil Analysis, Part 2. American Society of Agronomy, Madison, WI, USA, pp: 225-246. https://doi.org/10.2134/agronmonogr9.2.2ed.c13

Li X, Yu M, Ma J, Luo Z, Chen F, Yang Y, 2018. Identifying the relationship between soil properties and rice growth for improving consolidated land in the Yangtze River Delta, China. Sustainability 10: 3072. https://doi.org/10.3390/su10093072

Lin Y, Ye Y, Liu S, Wen J, Chen D, 2022. Effect mechanism of land consolidation on soil bacterial community: A case study in Eastern China. Int J Environ Res Public Health 19(2): 845. https://doi.org/10.3390/ijerph19020845

Liu J, Jin X, Xu W, Fan Y, Ren J, Zhang X, et al., 2019. Spatial coupling differentiation and development zoning trade-off of land space utilization efficiency in eastern China. Land Use Policy 85: 310-327. https://doi.org/10.1016/j.landusepol.2019.03.034

Mohebbi SMJ, 2014. Investigation of relationships between available phosphorus, potassium and some soil properties in agricultural lands of Varamin-Iran. Int J Agr Biosci 3: 7-12.

Nascente AS, Crusciol CAC, 2015. Soil aggregation, organic carbon concentration, and soil bulk density as affected by cover crop species in a no-tillage system. Rev Bras Ciênc Solo 39: 871-879. https://doi.org/10.1590/01000683rbcs20140388

Nelson DW, Sommers LE, 1982. Total carbon, organic carbon and organic matter. In: Methods of soil analysis. Part 2. Chemical and microbiological properties; Page AL, et al. (Eds.), American Society of Agronomy, SSSA Book Series, Madison, WI, USA, pp: 595-579.

Nguyen HQ, Warr P, 2020, Land consolidation as technical change: impacts on-farm and off-farm in rural Vietnam. World Dev 127: 104750. https://doi.org/10.1016/j.worlddev.2019.104750

Olsen SR, Sommers LE, 1982. Phosphorus. In: Methods of soil analysis. Part 2. Chemical and microbiological properties; Page AL et al. (Eds.). American Society of Agronomy, SSSA Book Series, Madison, WI, USA, pp: 403-430. https://doi.org/10.2134/agronmonogr9.2.2ed.c24

Oztekin T, 2013. Short-term effects of land leveling on irrigation-related some soil properties in a clay loam soil. Sci World J 2013: 187490. https://doi.org/10.1155/2013/187490

Parfitt JMB, Timm LC , Reichardt K, Pinto LFS, Pauletto EA, Castilhos DD, 2013. Chemical and biological attributes of a lowland soil affected by land consolidation. Pesqu Agropec Bras 48: 1489-1497. https://doi.org/10.1590/S0100-204X2013001100010

Parfitt JMB, Timm LC , Reichardt K, Pinto LFS, Pauletto EA, Castilhos DD, 2014. Impacts of land leveling on lowland soil physucal properties. Rev Bras Ciênc Solo 38: 315-326. https://doi.org/10.1590/S0100-06832014000100032

Parr M, Grossman JM, Reberg-Horton SC, Brinton C, Crozier C, 2011. Nitrogen delivery from legume cover crops in no-till organic corn production. Agron J 103: 1578-1590. https://doi.org/10.2134/agronj2011.0007

Powlson DS, Brookes PC, Christensen BT, 1997. Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. Soil Biol Biochem 19: 159-164. https://doi.org/10.1016/0038-0717(87)90076-9

Quintarelli V, Radicetti E, Allevato E, Stazi SR, Haider G, Abideen Z, et al., 2022. Cover crops for sustainable cropping systems: A review. Agriculture 12: 2076. https://doi.org/10.3390/agriculture12122076

Renkou LIF, Wenfeng X, Shungui T, Tongxu Z, Zhenqing L, Liping S, et al., 2020. The frontier and perspectives of soil chemistry in the new era. Acta Pedol Sinica 57: 1088-1104.

Robbins CW, Mackey BE, Freeborn LL, 1997. Improving exposed subsoil with fertilizers and crop rotations. Soil Sci Soc Am J 61:1221-1225. https://doi.org/10.2136/sssaj1997.03615995006100040030x

Sharifi A, Gorji M, Asadi H, Pourbabaee AA, 2014. Land consolidation and changes in soil properties in paddy fields of Gilan province, Iran. Paddy Water Environ 12: 139-145. https://doi.org/10.1007/s10333-013-0369-z

Shepherd TG, Saggar RH, Newman CW, 2001. Tillage induced changes in soil structure and soil organic matter fractions. Aust J Soil Res 39: 465-489. https://doi.org/10.1071/SR00018

Vance ED, Brookes PC, Jenkinson DS, 1987. An extraction method for measuring soil microbial biomass C. Soil Biol Biochem 19: 703-707. https://doi.org/10.1016/0038-0717(87)90052-6

Xue ED, Huang X, 2013. The impact of sewage sludge compost on tree peony growth and soil microbiological, and biochemical properties. Chemosphere 93: 583-589. https://doi.org/10.1016/j.chemosphere.2013.05.065

Yu G, Feng J, Che Y, Lin X, Hue L, Yang S, 2010. The identification and assessment of Ecological risks for land consolidation based on the anticipation of ecosystem stabilization: A case study in Hubei Province, China. Land Use Policy 27: 293-303. https://doi.org/10.1016/j.landusepol.2009.03.004

Zhang N, He X, Gao Y, Li Y, Wang H, Ma D, et al., 2010. Pedogenic carbonate and soil dehydrogenase activity in response to soil organic matter in *Artemisia ordosica* community. Pedosphere 20: 229-235. https://doi.org/10.1016/S1002-0160(10)60010-0

Zhang WH, Ma ZH, Zhang L, 2016. Effects of land consolidation period and tillage of hollowed villages on soil properties in Loess Plateau. Adv Eng Res 94: 122-124. https://doi.org/10.2991/icsd-16.2017.25