Variation in Soil Acidification Degree in Subtropical Croplands and Its Influencing Factors: Postprint

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Abstract

Accurately revealing the degree and causes of regional cropland soil acidification is of great significance for cropland quality improvement and sustainable agricultural development. This study utilized a 1:250,000 cropland soil database established from attributes of 36,777 surface cropland soil survey samples in 1982 and 236,445 samples in 2008 in subtropical Fujian Province, and investigated the degree and causes of province-wide cropland soil acidification over the 26-year period using GIS technology and a grey slope correlation analysis model, providing a scientific basis for provincial cropland soil acidity regulation. Results indicate that: Between 1982 and 2008, 67.60% of cropland soils in Fujian Province underwent acidification to varying degrees, with severe, moderate, and mild acidification areas accounting for 0.83%, 18.26%, and 48.52% of the total provincial cropland area, respectively. Regarding differences among administrative regions, severely acidified cropland was mainly distributed in Longyan City, accounting for 86.88% of the total severely acidified cropland area in the province, followed by Quanzhou City at 8.39%; moderately acidified cropland was primarily distributed in Nanping City, Longyan City, and Quanzhou City, accounting for 29.88%, 18.10%, and 16.94% of the total moderately acidified cropland area in the province, respectively, while mildly acidified cropland was scattered across all counties and cities in the province. From the perspective of soil type differences, gleyed paddy soil, percogenic paddy soil, and acidic purple soil subgroups had relatively large acidification area proportions, accounting for 82.87%, 72.37%, and 69.20% of their respective subgroup total areas; however, percogenic and stagnic paddy soil subgroups exhibited more severe acidification degrees, with severely, moderately, and mildly acidified percogenic and stagnic paddy soils accounting for 98.94%, 84.51%, and 87.36% of the corresponding total acidification areas in the province. Analysis of differences among land use types revealed that paddy fields and irrigated lands had relatively high acidification area proportions, accounting for 70.35% and 60.78% of their respective land use type total areas. The grey slope correlation analysis model indicated that acid rain, high-temperature and rainy climate, and heavy chemical fertilizer application were the main external causes of cropland soil acidification in Fujian Province between 1982 and 2008; therefore, strictly controlling industrial acidic waste gas emissions containing sulfur to thereby control acid rain and rationally adjusting fertilization structure are necessary approaches to mitigate province-wide cropland soil acidification.

Full Text

Preamble

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Soil Acidification Degree Difference and Impact Factors of Subtropical Cropland

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Abstract

Soil pH is an important indicator of cropland soil fertility and quality. Decline in soil pH represents a vital problem in soils of intensive agricultural systems in China, which heavily obstructs crop growth and ecological environment improvement. Accurate knowledge of the degree of acidification and its causes in regional cropland soils is crucial for enhancing cropland quality and achieving sustainable agricultural development. This study utilized a 1:250,000 cropland soil database constructed from 36,777 topsoil survey samples collected in 1982 and 236,445 samples from 2008 across Fujian Province, a subtropical region. Using GIS technology integrated with a grey slope correlation analysis model, we examined the extent of cropland soil acidification and its driving factors over the 26-year period to provide a scientific basis for soil acidity regulation at the provincial scale.

The results showed that 67.60% of cropland soils in Fujian experienced varying degrees of acidification between 1982 and 2008. Specifically, strongly, moderately, and weakly acidified areas accounted for 0.83%, 18.26%, and 48.52% of the total cropland area, respectively. At the prefectural level, strongly acidified cropland was mainly distributed in Longyan City (86.88% of the provincial total) and Quanzhou City (8.39%). Moderately acidified cropland was concentrated in Nanping City (29.88%), Longyan City (18.10%), and Quanzhou City (16.94%), while weakly acidified cropland was widespread across all counties. In terms of soil types, gley paddy soils, percogenic paddy soils, and acid purplish soils showed the highest acidification rates, with 82.87%, 72.37%, and 69.20% of their respective areas undergoing acidification. However, percogenic and hydromorphic paddy soils exhibited the most severe acidification degrees, with these two subgroups comprising 98.94%, 84.51%, and 87.36% of the total strongly, moderately, and weakly acidified cropland areas, respectively. Regarding land use types, paddy fields and irrigated fields showed higher acidification proportions, with acidified areas representing 70.35% and 60.78% of their respective totals.

Grey slope correlation analysis revealed that acid rain, high-temperature and rainy climate, and heavy fertilizer application were the primary external factors driving cropland soil acidification in Fujian. Therefore, strict control of industrial sulfur-containing acidic gas emissions to mitigate acid rain, coupled with rational adjustment of fertilization structure, constitutes a necessary approach to slow down cropland soil acidification across the province.

Keywords: Fujian Province; Farmland; Soil acidification; Soil subgroup; Land use type; Grey slope correlation analysis

Introduction

Soil acidification, manifested by continuous pH decline in high-input, high-output agricultural production systems, represents a major constraint to global agricultural productivity. Increased soil acidity not only causes nutrient leaching and fertility degradation but also severely impacts soil microbial communities and crop growth [1-3]. By the end of the 20th century, China’s acidified soil area had reached 2.04×10 hm^2, accounting for approximately 22.7% of the nation’s total soil area [4]. Consequently, accurately revealing the degree and causes of regional cropland soil acidification, and implementing scientific prevention and mitigation measures, have become critical issues for achieving sustainable agricultural development.

Numerous studies have investigated soil pH changes and influencing factors across different regions. Yang et al. [5] employed GIS spatial analysis to examine soil pH changes in northern China’ s grasslands from 1980–2000, finding an average pH decline of 0.63 units, with 95% of soils decreasing by 0.54–0.73 units. Guo et al. [6] analyzed soil pH data from 154 farmland plots across 35 Chinese regions in 1980 and 2000, concluding that heavy nitrogen fertilizer application was the primary cause of the 0.5-unit average pH decrease. At regional scales, Li et al. [7] reported that soil pH in the Chengdu Plain decreased from 6.95 to 6.70 (average 3.60% reduction) between 1982 and 2002. Liu et al. [8] found that most soils in the Taihu Lake region experienced varying degrees of acidification since the second national soil survey, with an average decline of 0.56 pH units. At the provincial level, Wang et al. [9] compared soil surface samples from Jiangsu Province' s second soil survey with those collected in 2003, revealing that while the general pattern of southern acidity and northern alkalinity persisted, local areas showed significant acidification. Zeng et al. [10] analyzed Guangdong Province' s cultivated land fertility survey data, demonstrating that emphasizing chemical fertilizers over organic manure since 1984 had accelerated paddy soil acidification. At the county scale, Liu et al. [11] used GIS to compare spatial variation in soil pH in Changtu County, Liaoning Province, between 1982 and 2011, showing a decline from 6.85 to 6.07 (annual decrease of 0.027 units). Si et al. [12] compared data from Xuan' en County, Hubei Province, revealing that brown soils and mountain yellow-brown soils derived from gravelly and quartz parent materials showed significantly greater pH declines than those from limestone.

These studies primarily focused on regional soil pH changes and spatial differences using simple linear correlation analysis, which cannot reveal the relative importance of different factors. Southern China' s subtropical regions experience high temperatures and abundant rainfall, leading to substantial base cation leaching and pronounced natural soil acidification. Combined with intensive multi-cropping systems that require heavy fertilizer application, cropland soil acidification has become a primary constraint on soil quality improvement in subtropical China. Therefore, this study selected Fujian Province as a representative subtropical region, using a 1:250,000 cropland use-soil type database constructed from 36,777 samples from the 1982 second national soil survey and 236,445 samples from the 2008 soil testing and fertilizer recommendation program. Integrating GIS technology with grey slope correlation analysis, we investigated differences in acidification degrees across various soil types and land use patterns over 26 years, providing scientific support for acidification control and improved utilization of subtropical cropland soils.

1. Materials and Methods

1.1 Study Area Overview

Fujian Province is located on China' s southeast coast between 23°30 -28°22 N and 115°50 -120°40 E. The region has a subtropical maritime monsoon climate with annual mean temperatures of 15.8-21.7°C, hottest month average temperature of 28°C, annual precipitation of 1,015-1,923 mm, annual sunshine duration of 1,700-2,300 h, annual solar radiation of 427×10^3-532×10^3 J·cm ^{2}, and 10°C accumulated temperature of 5,000-7,800°C. The terrain is dominated by mountains and hills, with generally higher elevation in the northwest and lower in the southeast. Parent materials primarily include residual slope deposits, alluvium, proluvium, marine deposits, aeolian deposits, and locally occurring oxbow lake sediments. By the end of 2008, the province' s total cropland area was 1.3417 million hm^2, dominated by paddy soils (93.05% of cropland), followed by latosolic red soils (4.32%) and red soils (1.21%). Other soil types (fluvo-aquic soils, yellow soils, coastal solonchaks, and purplish soils) occupied smaller areas [13].

1.2 Data Collection

The following data were collected from relevant authorities: (1) a 1:250,000 soil type distribution map of Fujian from 1982; (2) distribution maps and attribute data for 36,777 cropland topsoil survey samples from counties (cities, districts) in 1982; (3) GPS coordinates and attribute data for 236,445 topsoil samples from the 2008 soil testing and fertilizer recommendation program (including fertility surveys). From the Provincial Department of Land and Resources, we obtained the 2008 1:250,000 cropland use status map and DEM database. Annual statistical yearbooks for Fujian (1982-2008) and meteorological data from 66 weather stations were collected from provincial statistical and national meteorological bureaus. Since comprehensive acid rain monitoring in Fujian began in 2000, data from 48 acid rain monitoring stations (2000-2008) were obtained from the Provincial Environmental Protection Department to assess acid rain impacts.

1.3 Construction of Cropland Use-Soil Type Spatial Database

Using ARC/GIS software, cropland use type layers (dry land, paddy field, and irrigated field) were extracted from the 2008 1:250,000 land use status map database. The vectorized 1982 1:250,000 soil type database layer was overlaid with the cropland use type layer, and soil types showing changes were corrected based on field survey results to establish a 1:250,000 cropland use-soil type spatial database for Fujian. Using soil subgroups as evaluation units, the province' s cropland soils were divided into 34,593 evaluation units.

1.4 Construction of Survey Sample and Meteorological Station Spatial Databases

Based on the second soil survey sample distribution map and considering plot units and surrounding landscape features, the 36,777 survey samples from 1982 were manually digitized onto the cropland use-soil type spatial data layer using ARC/GIS software to generate the 1982 survey sample spatial layer. The 236,445 GPS coordinates from the 2008 soil testing program (including 236,445 samples with pH and organic matter data, and 29,945 samples with CEC, sand, silt, and clay data) were automatically linked to the cropland use-soil type spatial data layer using ARC/GIS "Add XY Data" tools to generate the 2008 survey sample spatial layer. These were then linked with the corresponding soil attribute databases to establish spatial and attribute databases for the 1982 and 2008 samples. Similarly, geographic coordinate data from 66 meteorological stations and 48 acid rain monitoring stations were linked to generate respective spatial layers, which were then connected to climate observation data and annual precipitation pH monitoring data to establish spatial and attribute databases for meteorological and acid rain monitoring stations.

1.5 Establishment of Relevant Attribute Spatial Databases

Key attributes included soil properties (CEC, pH, organic matter, sand, silt, clay), climate attributes (annual mean temperature and precipitation), acid rain attributes (annual precipitation pH), and fertilization attributes (annual nitrogen and phosphorus fertilizer application rates). Using ARC/GIS software, ordinary kriging interpolation [14] was applied to estimate spatial distributions of soil pH, organic matter, CEC, sand, silt, clay, and annual precipitation pH from point data. Annual mean temperature and precipitation were estimated using 3D trend surface analysis combined with inverse distance weighting residual correction [15]. These generated raster spatial databases for relevant attributes in 1982 and 2008. The cropland use-soil type spatial layer was used to mask these raster layers, and area-weighted averaging was applied by soil subgroup patches to calculate and establish spatial attribute databases for CEC, pH, organic matter, sand, silt, clay, annual mean temperature, annual precipitation, and annual precipitation pH. Using county administrative units, manual assignment methods were employed to establish spatial attribute databases for annual nitrogen and phosphorus fertilizer application rates.

1.6 Establishment of Cropland Soil Acidification Degree Spatial Database

Using ARC/GIS software, subtraction analysis was performed between the 2008 and 1982 cropland soil pH spatial distribution layers to obtain the pH change magnitude (ΔpH) for each evaluation unit. Soils with pH < 6.5 in 2008 and ΔpH < 0 were classified as acidified, while others were non-acidified. Using dynamic clustering analysis in DPS software, acidified cropland soils were categorized into three acidification degrees: weak acidification ($-0.50 < \Delta$pH < 0), moderate acidification ($-1.50 < \Delta$pH -0.50), and strong acidification (ΔpH -1.50).

1.7 Analysis of Factors Influencing Cropland Soil Acidification Degree

ΔpH values were extracted from the acidified soil pH change layer to establish a dependent variable sequence for acidification degree. Corresponding attribute values for relevant factors (CEC, organic matter, sand, silt, clay, annual mean temperature, annual precipitation, annual precipitation pH, annual nitrogen application rate, annual phosphorus application rate) were extracted to establish independent variable sequences. Using DPS statistical software, grey slope correlation analysis [16] was applied to calculate correlation coefficients between soil pH change magnitude and influencing factors, thereby analyzing the effects and relative importance of different factors.

1.8 Map Compilation

Maps showing cropland soil acidification degrees in Fujian were compiled using ARC/GIS software, with legends, scale bars, and north arrows added before final output.

2. Results

2.1 Analysis of Cropland Soil Acidification and Its Degree

The results (Table 1) revealed significant changes in soil acidity-alkalinity areas. In 1982, acidic and slightly acidic cropland soils accounted for 73.18% and 22.90% of the provincial total, respectively, while strongly acidic, neutral, and slightly alkaline soils represented only 0.23%, 3.48%, and 0.21%. By 2008, acidic and slightly acidic soils comprised 75.18% and 17.64%, while strongly acidic, neutral, and slightly alkaline soils represented 4.49%, 2.00%, and 0.24%. Over the 26-year period, strongly acidic and acidic soils increased by 4.26% and 2.00%, respectively, slightly alkaline soils increased by 0.03%, while slightly acidic and neutral soils decreased by 5.26% and 1.48%. In terms of acidity grade transitions, 75.30% of neutral soils shifted to slightly acidic, acidic, or strongly acidic categories, and 55.72% of slightly acidic soils transitioned to acidic or strongly acidic grades. Regarding pH changes, 33.05% of cropland soils showed pH reductions of 0–0.3 units, 31.52% decreased by 0.3–1.0 units, and 5.43% declined by more than 1.0 unit.

Analysis of acidification degrees (Table 2) showed that weakly, moderately, and strongly acidified cropland soils occupied 48.52%, 18.26%, and 0.83% of the provincial total area, respectively. Weakly acidified soils were widely distributed but concentrated in Nanping (20.71%), Sanming (17.66%), and Ningde (15.73%), followed by Zhangzhou (12.06%) and Fuzhou (11.79%). Moderately acidified soils were mainly found in Nanping (29.88%), Longyan (18.10%), and Quanzhou (16.94%), followed by Zhangzhou (10.58%) and Fuzhou (9.33%). Strongly acidified soils were relatively concentrated, primarily in Longyan (86.88% of provincial total) and Quanzhou (8.39%); no strongly acidified soils were found in Nanping, Putian, or Sanming. Overall, strongly and moderately acidified croplands were mainly distributed in northern (Nanping), southwestern (Longyan), and southeastern coastal (Quanzhou) regions, while weakly acidified croplands were concentrated in northern (Nanping, Ningde), western (Sanming), and eastern (Fuzhou, Zhangzhou) areas.

2.2 Analysis of Acidification Degree by Soil Type

Analysis of acidity type changes by soil subgroup (Table 3) revealed that percogenic paddy soil, gleyed paddy soil, and hydromorphic paddy soil showed the largest increases in strongly acidic area during 1982–2008, with percogenic paddy soil increasing most (6.11%). Of this increase, 66.21% and 36.00% originated from originally acidic and slightly acidic percogenic paddy soils, respectively. Acid purplish soil, salinized paddy soil, and latosolic red soil showed the greatest increases in acidic area, with acid purplish soil increasing by 39.23%, entirely converted from originally slightly acidic purplish soil. While slightly acidic cropland soil area generally decreased, coastal aeolian sand soil showed the largest increase (32.17%), all converted from originally neutral coastal aeolian sand soil.

Regarding acidification degrees (Table 4), all cropland soil subgroups except coastal solonchaks and salted-acid paddy soils experienced varying degrees of acidification. Percogenic and hydromorphic paddy soils dominated strongly acidified areas, together accounting for 98.94% of the provincial total. Percogenic paddy soil represented the largest moderately acidified area (71.91% of provincial total), followed by hydromorphic paddy soil, latosolic red soil, and gleyed paddy soil (combined 84.51%). Similarly, percogenic paddy soil dominated weakly acidified areas (74.77% of provincial total), with hydromorphic paddy soil, latosolic red soil, and gleyed paddy soil comprising 21.71% combined. These results indicate that percogenic and hydromorphic paddy soils experienced the most severe acidification in Fujian during the study period.

2.3 Analysis of Acidification Degree by Land Use Type

The results (Table 5) showed substantial differences in acidity-alkalinity changes among paddy fields, dry farming fields, and irrigated fields. In paddy fields, slightly acidic soil area decreased by 7.24% while acidic and strongly acidic areas increased by 2.34% and 5.38%, respectively, with 59.76%, 10.20%, 2.12%, and 0.10% of slightly acidic paddy soils converting to acidic, strongly acidic, neutral, and slightly alkaline categories. In irrigated fields, strongly acidic area increased by 0.30% (converted from acidic and slightly acidic soils), acidic area increased by 3.29% (15.26% converted from slightly acidic soils), and neutral area decreased by 15.63% (85.55% becoming slightly acidic, remainder acidic or strongly acidic). In dry farming fields, strongly acidic and slightly acidic areas increased by 1.57% and 3.17%, while acidic, neutral, and slightly alkaline areas decreased by 0.54%, 4.13%, and 0.06%, respectively, with complex conversion patterns among acidity grades.

Regarding acidification degrees (Table 6), 788.55×10^3 hm^2 of paddy fields (70.35% of total) experienced acidification during 1982–2008, with strong, moderate, and weak acidification representing 0.90%, 18.54%, and 50.91% of paddy field area, respectively. Irrigated fields showed acidification across 29.37×10^3 hm^2 (60.78% of total), with strong, moderate, and weak acidification comprising 0.11%, 24.01%, and 36.66%, respectively. Dry farming fields had relatively lower acidification, affecting 51.69% of total area, with strong, moderate, and weak acidification representing 0.59%, 14.80%, and 36.30%, respectively. Paddy fields showed the most severe acidification, followed by irrigated fields, while dry farming fields were least affected. Both paddy and dry farming fields were dominated by weak acidification, whereas irrigated fields showed substantial moderate and weak acidification.

2.4 Analysis of Factors Influencing Cropland Soil Acidification

Table 7 shows that CEC, clay content, annual precipitation pH, organic matter, and silt content were positively correlated with acidification degree, indicating that higher values of these factors weakened acidification (larger ΔpH). Conversely, annual precipitation, sand content, annual mean temperature, and phosphorus and nitrogen fertilizer application rates were negatively correlated, meaning higher values intensified acidification (smaller ΔpH).

The absolute values of grey correlation coefficients ($|R|$) between soil pH change magnitude and influencing factors followed the order: CEC > clay > annual precipitation pH > annual precipitation > organic matter > sand > annual mean temperature > phosphorus fertilizer > nitrogen fertilizer > silt. This indicates that CEC, clay, annual precipitation pH, annual precipitation, and organic matter had the most significant effects on acidification ($|R| > 0.850$). Sand, annual mean temperature, and phosphorus and nitrogen fertilizers had moderate effects ($0.800 < |R| < 0.850$), while silt had the weakest effect ($|R| < 0.790$). These results demonstrate that annual precipitation pH, precipitation, temperature, and nitrogen and phosphorus fertilizer applications were the main external drivers of acidification, while CEC, clay, organic matter, and sand content were key internal factors that mitigated or accelerated acidification.

3. Discussion

3.1 Effects of Precipitation and Temperature on Cropland Soil Acidification

Both natural and anthropogenic factors influence soil pH development. Natural factors determine long-term spatiotemporal pH variations during soil formation [17], as evidenced by China' s general pattern of southern acidity and northern alkalinity resulting from long-term climatic effects. Fujian' s subtropical climate features high temperatures (annual mean 15.8-21.7°C, hottest month 28°C) and abundant precipitation (1,015–1,923 mm annually), with 10°C accumulated temperature of 5,000–7,800°C [13]. These conditions intensify mineral decomposition and organic matter mineralization, causing substantial base cation leaching, reduced CEC and base saturation, and increased hydrogen saturation, leading to continuous acidification. Our results show strong relationships between soil pH change magnitude and both annual precipitation and temperature ($|R| = 0.898$ and 0.844, respectively), confirming that high temperature and precipitation were the primary natural factors causing acidification in 67.60% of Fujian' s cropland soils during 1982–2008. The high-precipitation northern region (Sanming and Nanping) accounted for 37.45% of the province' s acidified cropland area, while the warmer, slightly drier southeastern coastal region (Putian, Quanzhou, Xiamen, and Zhangzhou) contributed 27.28%.

3.2 Effects of Fertilization and Acid Rain on Cropland Soil Acidification

Short-term dramatic pH changes are primarily driven by anthropogenic disturbances [17]. Long-term unreasonable fertilization, particularly heavy application of acidic or physiologically acidic fertilizers, constitutes an important cause of soil acidification [18-19]. Acidic fertilizers (e.g., superphosphate) directly input acidic substances, while physiologically acidic fertilizers (e.g., ammonium sulfate) cause acidification through plant preferential uptake of NH , leaving SO ^{2} to combine with H released by crops, or through nitrification of NH that releases H [2,21]. Statistical data show that Fujian' s chemical fertilizer consumption increased continuously over the past 30 years, reaching 1.19×10 t in 2008—2.42 times the 1985 level—with nitrogen and phosphorus fertilizers dominating (39.90-60.77% and 13.51-17.25% of annual consumption, respectively). According to provincial statistical yearbooks, prefectures with severe acidification (Nanping, Quanzhou, Longyan, and Zhangzhou) had annual fertilizer application rates of 508-1,980 kg · hm ^{2}, 1.17-4.56 times the provincial average (434 kg · hm ^{2}), with acidic superphosphate dominating phosphorus applications [22]. Our results show strong correlations between soil pH change magnitude and annual phosphorus and nitrogen fertilizer rates ($|R| = 0.831$ and 0.807, respectively), indicating that long-term heavy application of acidic or physiologically acidic fertilizers was a major external driver of large-scale acidification.

Acid rain directly accelerates soil acidification through sulfate and nitrate ions [23]. Fujian belongs to China' s acid rain-sensitive zone, with severe acid rain occurring in northern, western, and southern regions, where cities like Longyan and Quanzhou have acid rain frequencies >50% [24]. Our results show an extremely strong correlation between soil pH change magnitude and annual precipitation pH ($|R| = 0.907$), significantly higher than other external factors. Thus, acid rain was the most important external cause of widespread cropland soil acidification in Fujian during 1982-2008. Monitoring data show that Nanping, Quanzhou, and Zhangzhou had annual precipitation pH values of 5.2, 5.1, and 4.6, respectively—0.9-1.4 units lower than the provincial average (6.0). This severe acid rain contributed to the large areas of strong and moderate acidification in these prefectures, which accounted for 95.27% and 75.49% of the provincial totals for strong and moderate acidification, respectively.

3.3 Effects of Land Use Patterns on Cropland Soil Acidification

Fujian' s subtropical climate with abundant light, heat, and water resources supports intensive multi-cropping systems, including tobacco-rice, rice-sweet potato, rice-vegetable, potato-double season rice, potato-middle season rice-sweet potato, and spring soybean-double season rice rotations [25]. Consequently, paddy fields predominantly practice upland-paddy rotation. Compared with continuous rice cultivation, upland-paddy rotation causes soil pH decline rates 10 times faster [26], making it more prone to acidification. This occurs because prolonged aerobic conditions enhance NH nitrification, and extended drainage periods oxidize ferrous iron, releasing protons that acidify soils [27]. Increased application of acidic or physiologically acidic fertilizers under this rotation further accelerates acidification [28]. Therefore, paddy fields and paddy soils experienced the most severe acidification during 1982-2008, with 70.35% of paddy fields showing varying acidification degrees. Irrigated fields, with more frequent irrigation than dry land but less leaching than paddy fields, also accumulate acid ions in surface soils through upward water movement [29], making them more susceptible to acidification than dry land. Consequently, 60.78% of irrigated fields experienced acidification, compared to 51.69% of dry farming fields.

3.4 Effects of Soil Intrinsic Properties on Cropland Soil Acidification

Short-term pH changes also depend on soil's inherent capacity to resist acid-base changes [17]. This buffering capacity, based on soil composition and geochemical properties, varies among soil types and influences acidification degree. Clay minerals and organic matter are primary sources of soil CEC [30]; thus, soils with high organic matter, clay content, and CEC have strong acid-buffering capacity and resist acidification, while sandy soils with low clay, organic matter, and CEC are vulnerable. Our results show strong correlations between soil pH change magnitude and CEC, clay, organic matter, and sand content ($|R| = 0.927$, 0.921, 0.851, and 0.848, respectively), indicating that differences in these intrinsic properties among soil types differentially affected acidification. Purplish soils and aeolian sand soils experienced severe acidification because purplish soil parent materials are predominantly purple sandstone and tuff with high sand content and low organic matter [19], while aeolian sand soils contain >85% sand with minimal clay and silt, providing weak protection for organic matter and intensifying mineralization [31]. These characteristics result in low CEC and weak buffering capacity, leading to widespread acidification. In contrast, fluvo-aquic soils showed limited acidification (38.43% of total area) because their location in alluvial plains with favorable irrigation and intensive management, including organic fertilizer application, resulted in higher clay, organic matter, and CEC contents with stronger acid-buffering capacity. Although coastal solonchaks have low clay content, their high original pH and abundant neutral salts provide high buffering capacity through neutralization reactions [32], making them the only soil type resistant to acidification in Fujian.

4. Conclusion

Between 1982 and 2008, 67.60% of cropland soils in subtropical Fujian experienced varying degrees of acidification. Strongly and moderately acidified croplands were mainly distributed in Longyan and Quanzhou cities. Percogenic and hydromorphic paddy soils dominated acidified areas, accounting for 98.94%, 84.51%, and 87.36% of strongly, moderately, and weakly acidified croplands, respectively. Paddy fields showed the most severe acidification (70.35% of area), while dry farming fields were least affected (51.69%). Grey correlation analysis ranked factors by absolute correlation coefficient: CEC > clay > annual precipitation pH > annual precipitation > organic matter > sand > annual mean temperature > phosphorus fertilizer > nitrogen fertilizer > silt. CEC, clay, annual precipitation pH, organic matter, and silt were positively correlated with acidification degree, while annual precipitation, sand, temperature, and fertilizer rates were negatively correlated. Fujian' s cropland soil acidification resulted from interactions between natural and anthropogenic factors, with acid rain, high-temperature and rainy climate, and heavy application of acidic or physiologically acidic fertilizers being the main external drivers.

While this study analyzed acidification degrees using large sample datasets from two periods, soil acidity management requires understanding both active and potential acidity to accurately calculate optimal amendment rates (e.g., lime, biochar). Future research should further elucidate relationships between active and potential acidity, establish scientific potential acidity estimation models, and accurately quantify potential acidity to provide scientific guidance for rational improvement of acidified cropland soils.

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