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Assessment and analysis of soil quality changes after eleven years of reclamation in subtropical China

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Abstract

Soil quality is one of the most important factors in sustaining the global biosphere and developing sustainable agricultural practices. It has been defined in several different ways in recent years from view points of bioproductivity, sustainability, environmental protection, and human and animal health. In this paper, soil quality refers to its capacity to meet the need of plant growth. Land use and management practices greatly impact the direction and degree of soil quality changes in time and space. Understanding the effects of land use and management practices on soil quality and its indicators has been identified as one of the most important goals for modern soil science. This paper presents a method for assessing and mapping soil quality changes in time and space in small watersheds. It was developed and used to evaluate the changes in soil quality after 11 years of reclamation at Qian-Yan-Zhou experimental station (QYZES), which is located in subtropical China. Changes in soil quality was assessed and analyzed for cropland, citrus orchards, pastureland, grassland, sparse weed land, artificial forests, natural forests, bare land and other land uses. The Qian-Yan-Zhou Soil Quality Information System (QYZSQIS) has been developed using ARC/INFO and FOXBASE software. Two concepts of Relative Soil Quality Index (RSQI) and its difference (ΔRSQI) are introduced and used in the evaluation and analyses. By combining the QYZSQIS with databases of soil properties for different time periods, the system provides an effective method for evaluating soil quality changes in time and space in small watersheds. The RSQI provides a standard for comparing regional soil quality and the ΔRSQI a standard for evaluating soil quality changes over time. After 11 years of reclamation, there was a decrease in the area of both low quality and high quality soils, while medium quality soils

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increased. In terms of land use systems, the soil quality in paddy fields, vegetable fields and citrus orchards was dominated by improvement, whereas fuel woods, sparse weed land, and bare land were mainly degraded. Annual grass played an important role in the conservation and improvement of soil quality in the area. Except for land uses and management practices, original soil quality level also plays a major role in soil quality changes. Soils with higher quality were degraded more rapidly, because they usually need more nutrient input to maintain their quality status than those with lower quality. These analyses show that it is of equal importance to improve soil quality in degraded locations and to sustain it in high-quality areas.

Keywords: soil quality; changes in time and space; soil degradation; GIS; subtropical China

1. Introduction

Human-induced soil changes and their effects on human lives and ecological environments have received extensive attention (Lal, 1990; Rozanov, 1990; Miller and Wali, 1994; Wang, 1995; Wang and Gong, 1996). Improving soil quality is one of the most important factors for sustaining the global biosphere (Smith et al., 1994). It is also the basis for the development of sustainable agriculture and may be used for evaluating and judging the sustainability of soil management practices and land use systems (Papendick and Parr, 1992; Karlen et al., 1994a,b; Smith et al., 1994). Soil quality and its importance in agricultural sustainability and environmental ecology have been recognized in recent years through several international symposia on soil quality (Rodale Institute, 1991; Smith et al., 1994).

Soil quality has been defined by many authors in recent years (Lal, 1991; Karlen et al., 1992, 1994a,b; Larson and Pierce, 1994; Doran and Parkin, 1994; Pennock and Van Kessel, 1997). These definitions are more or less different, but they always relate to the functions of the soil to supply nutrient and other physico-chemical conditions to plant growth, promote and sustain crop production, provide habitat to soil organisms, ameliorate environmental pollution, resist degradation, and maintain or improve human and animal health.

Land use and management practices greatly impact the direction and degree of soil quality changes. Owing to improper land use and management, soil erosion, acidification, nutrient depletion, pollution and other natural resource problems have been threatening human development (Lal, 1990; Rozanov, 1990). However, scientific land use and management usually improve soil quality and ecological environments (Rozanov, 1990; Cheng, 1993). While the competition for natural resources and food become more and more intensive, it is urgent to improve soil quality by maintaining or developing sustainable agricultural land use and management practices. This task is seen as one of the most important projects for modern soil science (Rozanov, 1990; Lal, 1993; Zhao et al., 1993; Cao et al., 1994; Wang and Gong, 1995, 1996).

Soil changes are dynamic over time (Jenny, 1961; Hoosbeek and Bryant, 1992; Li, 1995). Therefore, only by comparing and analyzing changes in soil properties between two or more time periods, can the essence and mechanism of soil changes be better understood. However, there are a number of deficiencies in current studies. These include:

(i) Evaluation work at regional levels does not directly reflect soil changes over time. For example, global assessment of human-induced soil degradation and the world map on status of human-induced soil degradation carried out by WRB (World Reference Base) and UNEP (United Nation Environmental Programme) (Oldeman, 1988; UNEP, 1990), mapping of soil degradation in China (Liu and Gong, 1995; Zhao, 1995), and the evaluation of soil degradation in South China (Sun et al., 1995; Zhao, 1995) etc., were carried out on the basis of current soil properties. Those studies could not, therefore, reflect the true nature of soil degradation as a dynamic process in time and space (Wang, 1994, 1995; Zhao, 1995). Furthermore, they could not differentiate between anthropogenic and natural processes of degradation (Wang, 1995; Zhao, 1995).

(ii) In studies on the impacts of land use on soil changes, many researchers evaluated the degree of soil degradation and soil improvement by comparing soil properties within the same time-period but under different land use patterns (Hu et al., 1993; Wang and Chen, 1993; Chen, 1995). This kind of approach may provide some level of explanation, but does not directly register soil changes. In addition, single soil property evaluations, such as changes in soil organic matter, N, P and K were usually emphasized, and much less attention was paid to a comprehensive assessment of soil quality changes. The results from different researchers are difficult to compare because of the different benchmark soils they used, and therefore, the rate of soil changes can not be accurately assessed and compared.

(iii) Though studies which monitor soil dynamics emphasize soil changes over time, and help in understanding the mechanism and processes of soil changes, they are usually confined to small plots, soil profiles, or laboratory soil columns. They do not, therefore, provide a comprehensive assessment and analysis of soil changes at a regional level.

Evaluation and monitoring of soil changes at farm and regional levels between different time-periods are vital to assess the direction and rate of change that land use and management practices have on soil resources, and to clearly define the mechanisms and processes of soil degradation and improvement.

The objectives of this study is to develop an effective method for evaluation of soil quality changes over time, and to reveal soil quality change status under various land use patterns and soil types. Hopefully, this approach will provide a tool to optimize land use, improve soil quality, understand processes that drive soil change, and to develop sustainable agricultural practices.

2. Method for evaluation of soil quality changes

2.1. Study site

This study was conducted at the Qian-Yan-Zhou experimental station of the Chinese Academy of Sciences (QYZES). Covering an area of 204.2 ha, QYZES is located in Taihe county, Jiangxi province, at 115° 57′E, 27° 42′N and has a subtropical climate and elevations from 66 to 131.5 m (Wang and Gong, 1995). The mean annual temperature is 18.6°C with an annual precipitation of about 1360 mm and 1785 hours sunshine. The relief is dominated by hills. According to the Chinese Soil Taxonomic Classification (First Proposal), the soils are classified into four soil groups and fifty species. The four soil groups are Red soils, Paddy soils (PS), Meadow soils (MS), and Umbrihumus Meadow soils (US). This approximately corresponds to the Haplic Acrisols, Aric Anthrosols, Eutric Fluvisols, and Umbric Fluvisols, respectively, in the FAO-UNESICO WORLD MAP Revised Legend. According to the soil parent materials, the Red soils are differentiated Argillaceous Red soils (AS) and Sandstone Red soils (SS). Table 1 shows some properties of the major soils.

Before 1983, QYZES was a very poor village with a lack of water and forest, poor soils, low yields, and extensive wasteland. In 1983, QYZES was provided with a detailed soil survey by the Chinese Academy of Sciences, and many important background data were obtained. It was then reclaimed under scientific guidance. In 1994, land utilization rate increased to 95% from the 10% in 1983. There are now more than 20 land use patterns including cropland, orchard land, forest land, shrubby land, pastureland, grassland, and bare land, which have been managed using common local measures and practices (Cheng, 1993). This provided a unique precondition for this study.

2.2. Soil sampling and laboratory analysis

Based on the 1983 detailed soil survey, surface soil samples (0–20 cm) were collected again in 1994 using a grid method (75 × 75 m). Additional samples were taken according to the natural conditions of the field, so that there was at least one sample point located in each land unit (Fig. 1). Vegetation, land cover, soil erosion condition, and other factors of each sample point were recorded. A total of 126 soil samples were taken.

Sixteen soil properties including soil organic matter (SOM), N, P, K, pH, base saturation, and texture were measured, using the same methods (ISS, 1978) as in 1983.

2.3. Development of soil information system and soil change data base

A soil quality information system of Qian-Yan-Zhou experimental station (QYZSQIS) was developed and used to evaluate and map soil quality and its

Table 1
Some properties of the major soils

Soils	Horizon	Depth (cm)	Color (dry)	Ph (H_2O)	C org (%)	Total N (%)	CEC (cmol(+)/kg)	Base saturation (%)
AS [a]	A	0–12	5YR 5/6	6.5	1.60	0.10	11.5	85.5
	AB	12–20	5YR 5/6	7.1	1.20	0.07	10.7	88.2
	B	20–50	2.5YR 5/8	7.6	0.80	0.03	10.1	90.5
	C	50–103	10YR 5/8	7.6	0.40	0.02	7.7	92.2
SS [b]	A	0–7	5YR 5/6	4.9	1.21	0.05	8.2	28.3
	B	7–27	5YR 6/8	5.0	0.65	0.04	7.3	19.1
	C	27–52	2.5YR 4/8	5.3	0.40	0.03	10.2	15.7
US [c]	A	0–14	7.5YR 4/2	5.3	3.50	0.16	20.5	28.5
	B	14–58	7.5YR 5/2	5.4	1.98	0.12	12.0	30.1
	C	58–93	7.5YR 6/2	5.6	1.01	0.08	10.3	35.2
MS [d]	A	0–11	10YR 4/3	7.5	1.05	0.10	15.3	84.7
	Br	11–69	10YR 5/8	8.1	0.45	0.50	10.4	98.8
	C	69–110	10YR 5/2	8.2	0.12	0.21	3.6	100
PS [e]	Ap_1	0–10	5YR 4/2	6.2	2.71	0.15	10.7	31.7
	Ap_2	10–20	5YR 5/2	6.5	1.80	0.09	10.6	37.9
	Bg	20–55	2.5YR 4/6	7.0	0.65	0.04	9.6	45.2
	BC	55–75	2.5YR 5/6	6.2	0.38	0.02	10.8	16.2

[a] Argillaceous Red soils.
[b] Sandstone Red soils.
[c] Paddy soils.
[d] Meadow soils.
[e] Umbrihumus Meadow soils.

changes. The system was built using PC-ARC/INFO and FOXBASE software. The steps in developing this system are summarized as follows:

Input related maps of relief, soils and land use to the computer database. This requires digitizing, editing and updating these maps, developing a DEM (digital elevation map), and producing a land unit map by editing an overlay of soil, relief and land use maps. Data related to soil quality in 1983 and 1994 were then added to the database and combined with the land unit map to calculate the relative soil quality indexes (RSQI) for 1983 and 1994, and the difference between them (ΔRSQI). We then evaluated soil quality, and produced the final database and maps of soil quality and its changes together with a statistical summary of the results.

The final database included map data for soil types, land use, relief, soil depth, attribute data (including basic soil properties — C, N, P, K, pH, base, texture, erosion conditions and land cover), profiles for 1983 and 1994, climate, and economic records. The QYZSQIS has the following functions: (1) database

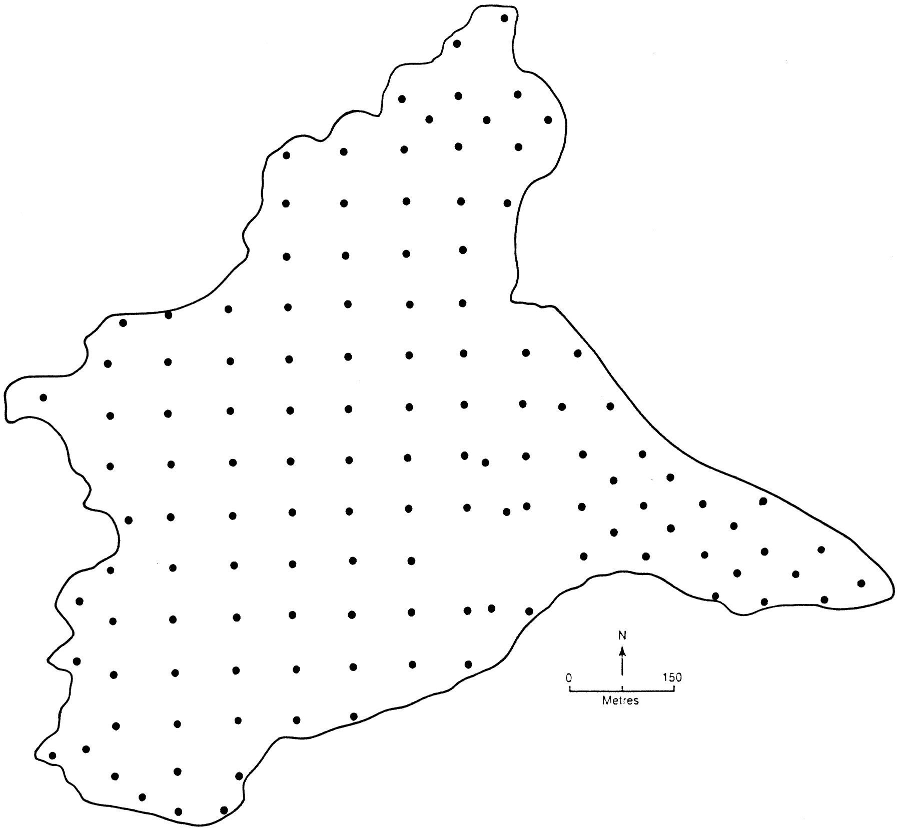

Fig. 1. Spatial distribution of soil sampling points.

management, (2) input, modification, editing, display, and output of maps, (3) evaluation of soil quality and its changes, (4) auto-inquiry for changes in soil quality and its indicators, and (5) spatial analysis.

2.4. Method for evaluation of changes in soil quality

2.4.1. Soil quality indicators

A soil quality indicator is a measurable soil property that affects the capacity of a soil to perform a specified function (Karlen et al., 1994a). For evaluation of soil quality, it is desirable to select indicators that are directly related to soil quality. Because soil quality assessment is purpose- and site-specific, indicators used by different researchers or in different regions may not be the same. According to the natural conditions of South China, 12 indicators were selected in this study. They include soil depth, texture, slope, SOM, total N, available N, total P, available P, total K, available K, cation exchange capacity (CEC), and pH. Soil depth and texture reflect the suitability of soil physical conditions for plant growth. Slope and texture are related to resistance of the soil to erosion.

SOM, N, P, and K show the nutrient status of the soil for plants. SOM, CEC and pH influence the habitat for soil organisms. Soil texture, slope, depth and SOM relate to plant available water. These factors have therefore been adopted to reflect the various aspects of soil quality in relation to plant growth.

2.4.2. Subdivision of the indicators and their marks

Each of the indicators was divided into four classes (I, II, III, IV). Class I is the most suitable for plant growth, class II suitable to plant growth but with slight limitations, class III with more serious limitation than class II, and class IV with severe limitations for plant growth.

The range for each class, which was based on research knowledge from many years in the hilly region of subtropical China, is shown in Table 2. Marks of 4, 3, 2 and 1 were given to class I, II, III and IV, respectively.

2.4.3. Weights of the indicators

The contribution or importance to soil quality of each indicator is usually different, and can be indicated by a weighting coefficient. There are many ways to assign the weights for each indicator. This includes experience, mathematical statistics, or models (Wang, 1994). In this paper, the weight for each indicator (Table 2) has been assigned on the basis of research experience in South China. The sum of all weights was normalized to 100%.

2.4.4. Quantitative evaluation of changes in soil quality

By introducing the concept of relative soil quality index (RSQI), and with the assistance of a geographical information system (GIS), the 12 indicators were combined into an RSQI.

The equation for calculating RSQI value is:

$$RSQI = (SQI/SQI_m) \times 100 \quad (1)$$

where SQI is soil quality index, SQI_m is the maximum value of SQI.

Table 2
Soil quality indicators and their weights and classes for the evaluation of soil quality in QYZES

Indicators	Weights	I	II	III	IV
Soil depth (cm)	13	> 100	80–100	50–80	< 50
Texture	11	loam	Clay or sandy loam	clay or sand	grit
Slope	13	0–5°	5–10°	10–20°	> 20°
Organic matter (g/kg)	13	> 30	20–30	10–20	< 10
Total N (g/kg)	6	> 2.0	1.25–2.0	0.75–1.25	< 0.75
Total P (g/kg)	6	> 1.5	1.0–1.5	0.5–1.0	< 0.5
Total K (g/kg)	5	> 25	17.5–25	10–17.5	< 10
Available N (mg/kg)	6	> 200	150–200	100–150	< 100
Available P (mg/kg)	6	> 15	10–15	5–10	< 5
Available K (mg/kg)	6	> 150	100–150	50–100	< 50
CEC (cmol (+)/kg)	10	> 15	10–15	5–10	< 5
pH	5	5.5–7.0	5.0–5.5	4.5–5.0	< 4.5

SQI is calculated from the equation:

$$\mathrm{SQI} = \sum W_i I_i \qquad (2)$$

where W_i are the weights of the indicators, I_i the marks of the indicator classes. For example, if the slope of a soil is 7°, it belongs to class II (Table 2). As the weight for slope is 13, and the mark for class II is 3, then the $\mathrm{SQI}_{slope} = 13 \times 3 = 39$. In this way, SQI for every indicator can be calculated. Therefore, the SQI value for a soil can be produced by summing up its 12 indicator-SQI values. The maximum value of SQI for the soil is 400 and the minimum value 100.

An optimal soil in any region will have a normalized RSQI of 100, but real soils will have lower values which indicate directly their distance from the optimal soil. By computing RSQI values, soil quality in different regions can be compared even if they are evaluated with different evaluation systems, weightings, and classes. Similarly, the ΔRSQI could quantify changes in soil quality in a comparable way between two regions.

According to the RSQI values, soils in Qian-Yan-Zhou experimental station were classified into 5 classes from best to worst, represented as follows by I, II, III, IV and V, respectively.

Classes	RSQI Value
I	90–100
II	80–90
III	70–80
IV	60–70
V	< 60

Changes in soil quality (ΔRSQI) were grouped into six classes differentiated as follows:

Change classes	ΔRSQI
Great increase	> 10
Moderate increase	5–10
Slight increase	0–5
Slight decrease	-5–0
Moderate decrease	-10–-5
Great decrease	< -10

3. Results and discussion

3.1. General changes in soil quality

Soil quality evaluations using data from before reclamation in 1983 and after 11 years of reclamation showed that soil quality at this experimental station was

Table 3
General soil quality changes in areas for different soil types following 11 years of reclamation (ha)

Classes	Time	AS	SS	PS	MS	US	Total
I	1983	0.0	0.0	0.0	0.0	0.0	0.0
	1994	0.0	0.0	0.0	0.0	0.0	0.0
II	1983	2.4	0.0	0.0	0.0	3.8	6.2
	1994	0.7	0.0	0.0	0.0	0.4	1.1
III	1983	8.6	6.6	0.0	0.0	5.8	21.0
	1994	18.9	6.9	9.5	21.0	7.9	64.2
IV	1983	46.1	44.3	14.6	23.3	0.0	128.3
	1994	37.1	39.4	5.1	11.5	1.3	94.4
V	1983	6.3	21.2	0.0	9.3	0.0	36.8
	1994	6.7	25.8	0.0	0.1	0.0	32.6

still not very high. In 1983, there was no class I soil, and areas with class II, III, IV and V quality accounted for 3.2% (6.2 ha), 11.0% (21.1 ha.), 66.7% (128.3 ha) and 19.1% (36.8 ha) of the total soil area, respectively. Paddy and Meadow soils had lowest quality, all belonging to class IV or V (Table 3, Fig. 2).

After management for 11 years, areas of class IV and class V were reduced to 49.1% (94.4 ha) and 17.0% (32.6 ha), respectively. The class III soil increased significantly to 33.4% (64.2 ha), three times of that in 1983. However, area of class II shrank by 5.1 ha (82.5% of that in 1983). This indicates that reclamation efforts improved low quality soils, but some high quality soils were not maintained. The major reason is the reclamation only focused on improving poor soils, but neglected conserving high-quality soils (Wang, 1995). Actually, high-quality and low-quality soils should be managed in different ways because of their different bioproductivity and nutrient losses.

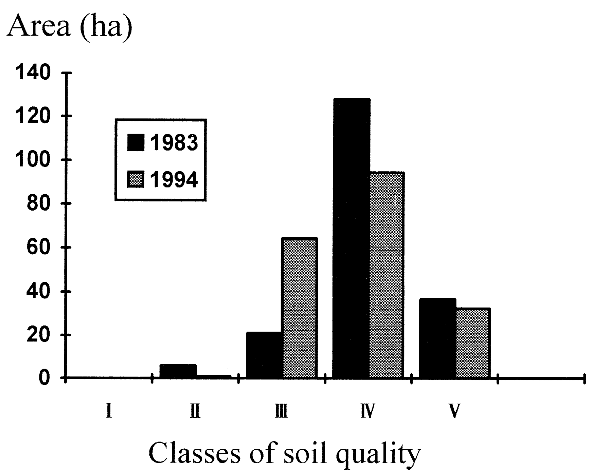

Fig. 2. General changes in soil quality after 11 years of reclamation in QYZES.

Among all of the soil types, Meadow soils and Paddy soils showed the greatest improvement in quality. Meadow soils in 1983 were predominantly class IV and V. By 1994, class V soil had almost disappeared, and class IV soil had decreased by 50.7% compared to 1983. Class III soil had expand its area significantly, showing soil quality had been improved substantially. Similarly, most (65%) of the paddy soils belonging to class IV before reclamation were improved to class III.

Contrary to the improvement in the Meadow and Paddy soils, the other three soil types have been degraded, especially the Umbrihumus Meadow soils (Table 2). The Umbrihumus Meadow soils had higher quality in 1983, with 39.4% in class II and 60.6% in class III. After 11 years of reclamation, the area of class II soil decreased to 4.1%, and moreover, about 1.3 ha of new class IV soil has appeared. This emphasizes that the maintenance of high quality soil is as important as the improvement of low quality soil.

3.2. Characteristics of soil quality changes for different soil types under various land use systems

In cultivated land, paddy fields, vegetable fields and uplands showed different changes in soil quality. In paddy fields, soil quality has been generally improved because of the better fertilization, management, and rotation with green manure and legumes. Fig. 3 shows that the RSQI values in Argillaceous Red soils, Sandstone Red soils, Paddy Soils, and Meadow soils increased compared with 1983, particularly for Meadow and Paddy soils. Even in the Umbrihumus Meadow soil, soil quality remained at the original average level. Soil quality in vegetable fields also increased, except for the reclaimed areas of Argillaceous Red soils. However, upland soil quality decreased (Fig. 3). Changes in soil quality in the paddy and vegetable fields are therefore better than that in the upland.

Citrus is locally the most important tree cash crop, and is usually given higher inputs and managed intensively. The average soil quality in citrus orchards developed on Argillaceous Red soils, Sandstone Red soils, Paddy soils and Meadow soils showed some increase. The averaged RSQI value of citrus orchards on Argillaceous Red soils increased by 1.8, that in Paddy soil and Sandstone Red soil by about 5.0, and in Meadow soil by 11.2. However, the RSQI value in the citrus garden in Umbrihumus Meadow soil decreased by 3.4 compared with 1983. Soil quality changes in citrus orchards thus showed a similar trend to that found in paddy fields (Fig. 3).

Coniferous forests and mixed forests of coniferous and broadleaf trees covered the largest area among all of the land use patterns at the experimental station. Slash pine, Masson pine, and mixed forests of coniferous and broadleaf trees grown on Argillaceous Red soils and Sandstone Red soils retained almost the same levels of soil quality. After growing coniferous trees, soil quality on

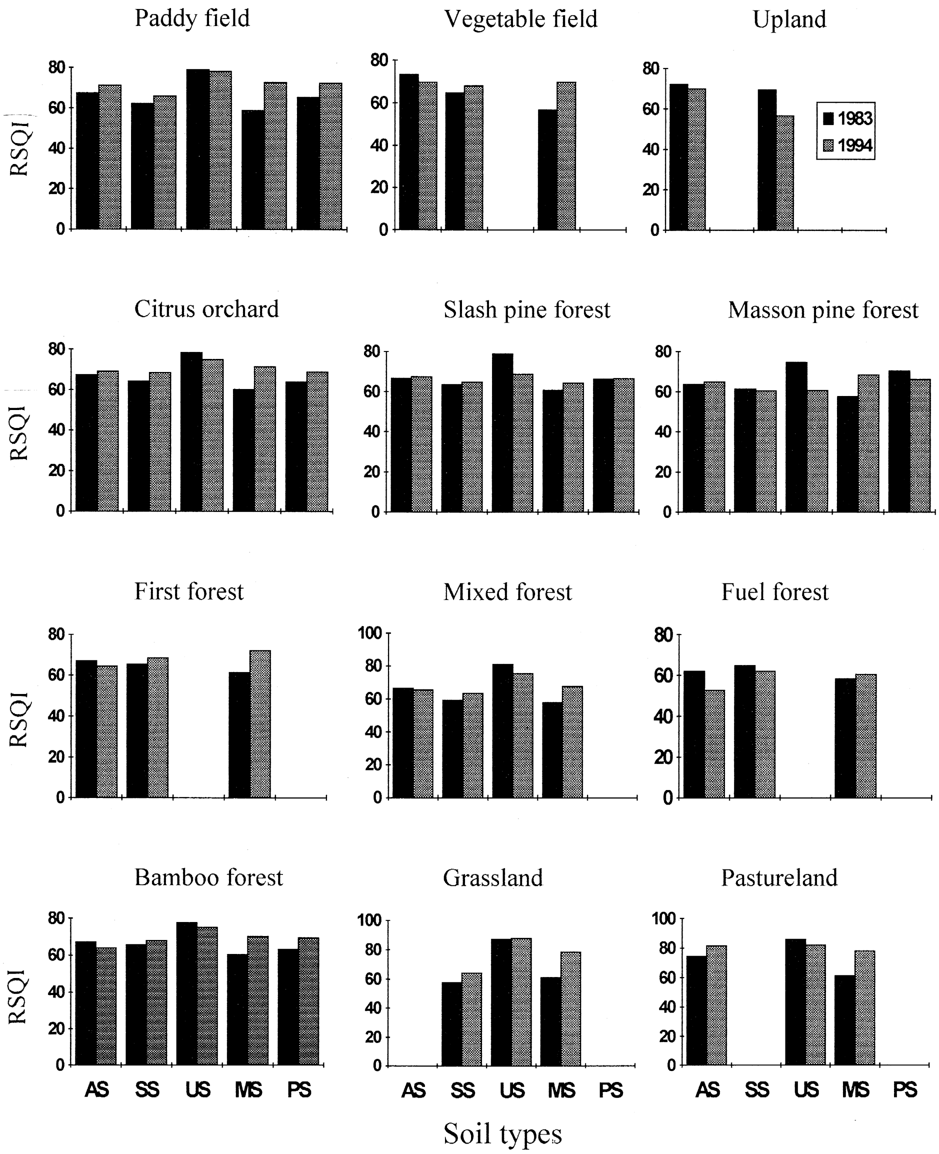

Fig. 3. Soil quality changes under various land use systems after 11 years of reclamation.

Umbrihumus Meadow soil decreased, more markedly for Masson pine and slash pine forests, and to a lesser extent for the mixed forests. However, those grown in Meadow soils showed some improvement in soil quality (Fig. 3).

In bamboo forests, soil quality increased for Meadow soil, Paddy soil, and Sandstone Red soil, and decreased for Umbrihumus Meadow soil and Argillaceous Red soil, but only over a narrow range. Soil quality for the fuel woods decreased more significantly than for bamboo forest (Fig. 3).

Natural grassland and pasture land have shown the greatest improvement in soil quality because of their enormous underground biomass. RSQI values in Meadow soil and two kinds of Red soils increased by 7 to 18. Owing to the higher quality before reclamation, Umbrihumus Meadow soils kept their previous quality level under natural grass vegetation, but showed a slight decrease in its RSQI value (by 3.80) after 11 years of pasture (Fig. 3).

In summary, directions and intensity of changes in soil quality were different for different land use systems. The direction and intensity were also greatly influenced by the original quality level and soil type. Therefore, we can not simply conclude that a land use system leads to a constant change in soil quality. According to our results, the quality of Meadow soil under various land use patterns was improved after reclamation, more for paddy and vegetable fields, and less for fuel woods, upland and coniferous forests. The main reason is the Meadow soil had the lowest original quality. Umbrihumus Meadow soil was the richest soil in the station before 1983, but after 11 years of reclamation, its quality had fallen to some degree or at most kept its previous levels under various land use patterns. Soil quality of the Red and Paddy soils became better after being utilized as paddy field, vegetable field, citrus orchard, or grassland; and became worse or unchanged after being utilized as upland, fuel woods, or coniferous forests. This indicated that paddy field, vegetable field, citrus orchards, and grassland uses may help to maintain or improve soil quality.

3.3. Quantitative assessment of changes in soil quality

Based on changes of RSQI (ΔRSQI) from 1983 to 1994, soil quality changes under various land use systems and soil types were evaluated quantitatively and mapped (Fig. 4). In the computer database, this map and its connected data on soil quality changes can be used to display the detailed change conditions for various land use systems, soil types and relief conditions in the study area. As an example, the results of changes in soil quality under various land use systems are discussed here (Table 4).

The results in Table 4 indicated that 75.9% (6.3 ha) of the total area of paddy field had improved soil quality with a ΔRSQI above zero, and 72.3% (6.0 ha) above 5. More than 50% of the vegetable field had a ΔRSQI above 0; 90.1% of the upland had a ΔRSQI below zero, showing that soil quality in most of the paddy field and vegetable field was increased, while upland soil quality fell.

Soil quality in citrus gardens was dominated by improvement. Of the soil in citrus orchards, 40.2% (14.7 ha) had a ΔRSQI above 10, 67.2% (24.6 ha) above 5, and 72.1% (26.4 ha) above 0. These soils were mainly Meadow or Paddy soils with lower fertility distributed on the flat stream terrace. After citrus trees were grown, they usually received careful management and high inputs, consequently improving soil quality. However, about 28% of the citrus orchard soil decreased in quality. These citrus orchards were usually located on slopes with

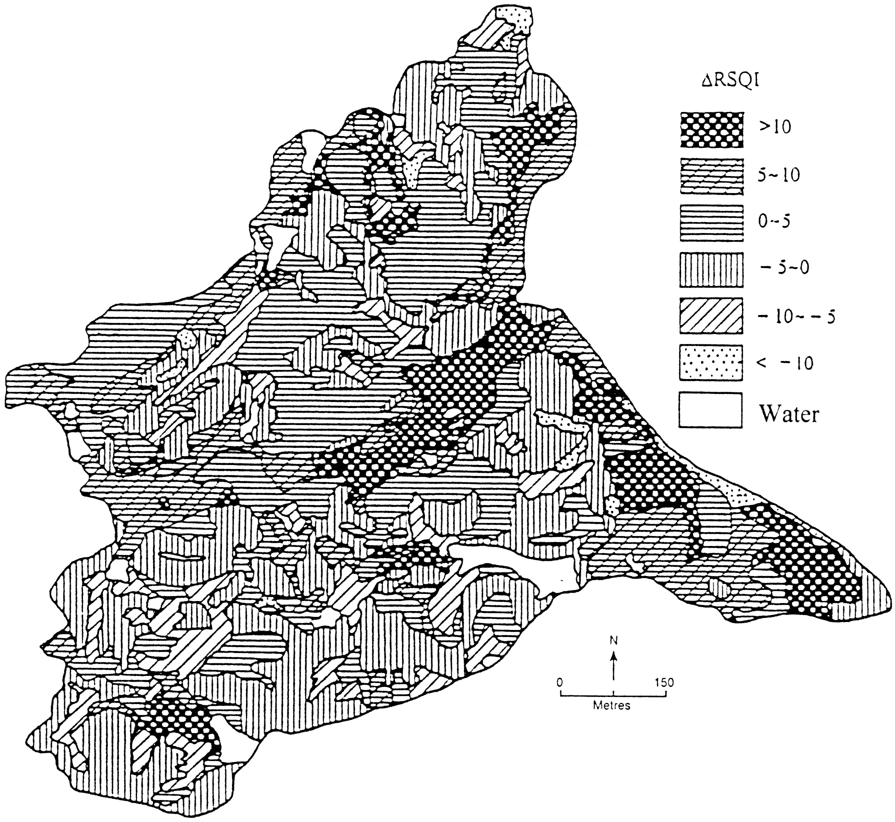

Fig. 4. The assessment map of changes in soil quality after 11 years of reclamation in QYZES.

Red soils of initial high quality, which proved difficult to maintain. On the other hand, these orchards were usually given less input and less intensive management than those on terraces because the slopes made soil management more difficult.

Changes in soil quality in the coniferous forests and mixed forests of coniferous and broadleaf were generally not significant, and most of the ΔRSQI values ranged from -5 to $+5$. However, where low fertility soil, i.e. the eroded Red soil, was planted with coniferous trees, its RSQI value was usually increased significantly. For the high fertility soil, i.e. high organic matter thick Red soil, considerable decrease in RSQI was usually observed (Wang, 1995). This indicated that for low fertility soil, coniferous trees are good pioneer tree species to improve soil quality as well as produce wood, but for high fertility soil, they can not maintain the original fertility level and may decrease soil quality.

In pastureland, soil quality was improved very significantly. Of the total area, 73.3% had a ΔRSQI above 5, and 64.9% above 10. Only a small part had a

Table 4
Changes in area for the different ΔRSQI classes from 1983 to 1994 under various land uses (ha)

Land use	Total area (ha)	> 10	5–10	0–5	−5–0	−10– −5	< −10
Paddy field	8.3	0.9	5.1	0.3	2.0	0.0	0.0
Upland	0.7	0.0	0.0	0.0	0.5	0.2	0.0
Vegetable field	0.6	0.3	0.1	0.0	0.1	0.1	0.0
Citrus orchard	36.6	14.7	9.9	1.8	8.5	1.6	0.1
Hawthorn orchard	0.2	0.0	0.0	0.0	0.2	0.0	0.0
Chestnut orchard	0.2	0.0	0.0	0.0	0.2	0.0	0.0
Masson pine forest	47.8	1.0	0.7	26.9	13.3	5.6	0.2
Slash pine forest	41.3	0.5	6.3	9.3	23.6	1.5	0.1
Fir forest	5.4	0.1	0.2	2.2	1.7	1.1	0.1
Mixed forest	12.2	0.5	0.3	2.8	7.8	0.9	0.0
Broadleaf forest	5.9	0.0	0.7	2.6	1.9	0.0	0.8
Fuel woods	2.5	0.0	0.0	1.7	0.6	0.0	0.2
Bamboo forest	12.4	0.4	6.9	4.0	0.3	0.5	0.2
Bush	0.4	0.0	0.4	0.0	0.0	0.0	0.0
Paulownia forest	0.2	0.0	0.0	0.2	0.0	0.0	0.0
Oil-tea	1.7	0.0	0.2	0.9	0.6	0.0	0.0
Tung oil trees	0.6	0.0	0.0	0.4	0.2	0.0	0.0
Pasture land	2.8	1.8	0.2	0.2	0.6	0.0	0.0
Grassland	2.3	0.7	0.1	1.2	0.2	0.1	0.0
Sparse weed land	10.0	0.0	0.0	3.2	1.6	4.5	0.7
Bare land	0.3	0.0	0.0	0.0	0.1	0.1	0.1
Total (ha)	192.4	20.8	31.2	57.8	63.9	16.2	2.5

ΔRSQI between −5 and 0. This occurred mainly on the Umbrihumus Meadow soils with a high soil organic matter, where soil quality was influenced by the rapid decomposition of the organic matter after transformation to pasture. Soil quality in natural grassland was also characterized by an increase because of the grass density, but it was less significant than that in pastureland. Most of the sparse grassland and all of the bare land degraded in soil quality (Table 4).

4. Conclusion

The combination of a soil change database with a GIS has proved an effective method for evaluating and mapping changes in soil quality at small scales. This study provided basic data as well as a method for monitoring and evaluation of changes in soil quality in small areas. The method is also helpful for studying soil changes, soil degradation, evaluation of soil quality and sustainability at regional levels.

RSQI could serve as a unified criterion for comparing regional soil quality, and ΔRSQI provides a standard for the evaluation of soil quality changes.

Changes in soil quality are controlled mainly by the land uses, management practices, and soil types. Grass plays a very important role in conservation and improvement of soil quality in subtropical China. Changes in soil quality for citrus orchards and paddy fields were mainly influenced by the management practices and input levels, while for coniferous forests it mainly reflected the original soil quality. Soils with high fertility have a tendency to become degraded. It is of great importance to both improve low quality soils and conserve high quality soils.

Unless the concept of time and initial conditions are considered in the study of changes in soil quality, it is difficult to demonstrate the increase or decrease of soil quality, and the improvement or degradation of soil fertility.

Although this study has produced some useful results about soil quality changes in time and space, yet, limited by the background data, it mainly focuses on surface soil properties and the soil function to support plant growth. Our approach may not provide a truly integrated assessment of soil quality. It is our hope to consider subsoil attributes, more indicators, and other soil functions (i.e. a buffer against degradation and environmental contamination) in future refinement. Also, we would like to extrapolate this research to other areas.

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