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Quantitative and qualitative soil quality assessments of tea enterprises in Northern Vietnam

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Long-term cultivation of tea (Camellia sinensis (L) O. Kuntze) in the northern mountainous zone of Vietnam has resulted in soil quality degradation that could affect economic development in the region if sustainable production practices are not identified. The objective of the study is to identify appropriate indicators for assessing soil quality on tea plantations. Quantitative (based on soil analysis) and qualitative (based on farmer interviews) indicators were defined based on their sensitivity to change. Key quantitative indicators were organic-C, pH, N, P, K and S concentration (chemical), mechanical resistance, bulk density, total porosity, PAWC (plant available water capacity) and MWD (mean weight diameter) of aggregates (physical), and earthworm populations (biological). Decreases in the organic-C, N, K and S content, pH, total porosity, PAWC, MWD and earthworm populations, or increases in bulk density and mechanical resistance (compaction) indicated a decrease in soil quality due to long-term tea production. Qualitative assessments gathered through farmer interviews were also used to evaluate overall efficiency of current management practices to sustain long-term tea production. Farmers commonly assess soil quality in terms of tactile or visual soil properties. Important indicators based upon farmers' perceptions were (in order) organic matter, fertility, soil compaction, soil structure, moisture retention, earthworm abundance, erosion, acidity, surface's thickness and the incidence of weeds. Farmer observations of soil quality changes were generally in good agreement with the quantitative assessments. To ensure adoption of improved management practices, qualitative soil quality information obtained from on-farm surveys should be used to supplement the quantitative data obtained through soil analyses.

Key words: Soil quality, indicators, tea cultivation.

INTRODUCTION

Tea is a major perennial cash crop in the humid areas of the northern mountainous zone of Vietnam. The tea production system, like that of many other upland crops in Vietnam and throughout south-east Asia, is undergoing major changes in response to population pressure and improved market access. As a consequence, there has been an increase in both land-use intensity and soil degradation (Pandey, 1996).

Whereas tea plantations remain productive for long periods, yields tend to decline in the latter years. This drop in productivity is traditionally attributed to natural aging of the plants (Do, 1980), although there is some speculation that it may also reflect a loss of soil quality. To be sure, degradation in soil quality is often associated with the type of intensive land use involved in tea production. Moreover, because crop growth and productivity are a reflection of soil quality, any degradation of the soil can be expected to adversely affect the stability of system. Therefore, it was deemed that an evaluation of soil quality changes during long-term tea production could help enhance the sustainability of tea cultivation in Vietnam.

The first step in a study such as this is defining what is meant by "soil quality", and then identifying those indicators that will be most useful in monitoring its change. We have adopted the definition of soil quality espoused by Doran and Parkin (1994); that is, a soil's quality is its capacity to support plant growth. To be useful, soil quality indicators must provide a sensitive and timely measure of the soil's ability to function and be able to identify whether the change in soil quality is induced by natural processes or occurs as a result of management (Doran and Parkin, 1994; Burger and Kelting, 1998). There are two common approaches to assessing soil quality: qualitative and quantitative. Harris and Bezdicek (1994) defined qualitative and quantitative assessment based on characteristics of the diagnostic properties of soil quality such as descriptive and analytical. Descriptive approaches uses words as descriptors, and hence, are inherently qualitative or subjective. In contrast, quantitative approaches use analytical measurement and specific units as descriptors.

Qualitative soil quality indicators are often described and recorded through direct observation. The use of indigenous knowledge and experience of farmers provides a simple approach to characterize the status and diagnose any changes in soil quality (Romig et al., 1995). Farmers' indigenous knowledge, which develops from their practical experience, could be used to calibrate measured values, providing a more meaningful description of soil quality (Harris and Bezdicek, 1994). Farmers usually describe soil properties based on look, smell, feel and taste (Harris and Bezdicek, 1994; Garlynd et al., 1994).

Quantitative assessments are more sophisticated procedures involving analytical data (Harris and Bezdicek, 1994). Several techniques or methods have been developed to quantify soil quality indicators. These include the comparative approach (Pierce and Larson, 1994), dynamic approach using statistical quality control procedures (Pierce and Larson, 1994; Pierce and Gilliand, 1997), computer models (Pierce et al., 1983; Larson and Pierce, 1994; Burger and Kelting, 1998), multi-scale approach (Karlen et al., 1997) and performance-based scale index (Doran and Parkin, 1994). Among these methods, monitoring of dynamic soil properties is a very important method because these properties are always in state of flux as they respond to environmental and management forces (Pierce and Larson, 1994).

The objective of this study was to identify appropriate indicators for assessing the impact of long-term tea cultivation on soil quality in the northern mountainous zone of Vietnam.

MATERIALS AND METHODS

Quantitative approach (soil analysis)

Study site and soil sampling procedures

The study was conducted during 2001-2002 in the Song Cau tea enterprise of Thai Nguyen province, the largest tea area in the northern mountainous zone of Vietnam. Slope of the site is gentle and approximate 10-15 %. The study soils are clayey with clay contents as high as 42 to 46% in the surface layer and increasing with depth. The soils are moderately deep with little mixing of stones in the surface horizons. The typical reddish yellow color is an indication that oxidizing conditions predominate, with Fe- and Al-oxides being the most abundant elements. These soils were classified as Kanhaplustult Ultisols (Dang and Anderson, 2000).

The study was based on chronosequence approach which represents an ecological time series of soil where the differences in age or time are selected but not differences in environmental conditions (Dyck and Cole, 1994). This method is often used to define the degree of soil degradation or improvement by comparing soil properties under the same or different land use patterns but having different land use periods (Hu et al., 1993). Based on such approach, field sites were selected based on age of the tea plantation; that is, native forest (control), 10, 25, and 40 year old tea plantations. Each age class was replicated at least three times. All the tea fields had the same cultivation history in which tea was the first crop after clearing forest for cultivation. Tea plantations received the same fertilizer inputs (about 150, 80 and 80 kg ha $^{-1}$ yr $^{-1}$ of N, P and K fertilizers, respectively). Tillage was not often applied when the tea crop matures because tea rows were covered by plants' canopy.

Chemical analyses were conducted using composite samples (n = 5) collected from three girds (7 x 10 m) within each field. Soils were collected at three depths (0–10, 10–20, and 20–40 cm), with each depth increment analyzed separately. Soil samples analyzed for physical properties (at the 0–20 cm depth only) were collected separately.

Earthworm populations, representative of biological indicators, were monitored monthly throughout the rainy season (July-November). Five randomly collected soil samples (25 × 25 × 20 cm) were passed through a 10 mm sieve to recover the soil fauna.

Laboratory methods

Soil organic carbon and total-N and -S were determined by combustion, using a LECO CNS-2000. Total soil P and K, which were analyzed to understand their accumulation in acid soils, were extracted using an H_2SO_4-H_2O_2 digestion (Thomas et al., 1967). Phosphate in the digests was measured calorimetrically, using a Technicon autoanalyser; K in the extracts was determined using atomic emission spectrometry (AES). Total soil Cd, which is an important element in acid soils, was extracted by digestion with a mixture of concentrated HNO_3, $HClO_4$ and HF (Sheldrick, 1984) and determined using atomic absorption spectrometry (AAS). Soil pH was determined using a 1:1 (w/w) soil: water extract of the composite sample. Plant available K was extracted using a cationic resin exchange membrane (Qian et al., 1992) and determined using AES. Exchangeable cations (that is, Ca, Mg, K, Na, and Al) were extracted using unbufferred 0.1 M $BaCl_2$ (Hendershot et al., 1993) and determined using AAS. Bulk density was estimated using the core method described by Kalra and Maynard (1991). Plant available water-holding capacity (PAWC) was calculated as the difference between field capacity and the permanent wilting point–determined using a pressure chamber apparatus (Anderson and Ingram, 1993). Aggregate mean weight diameter (MWD) was determined by wet sieving (Angers and Mehuys, 1993). Soil mechanical resistance was measured using a base surface cone penetrometer (Davidson, 1965).

Qualitative approach (farmer interviews)

The survey was conducted at the same time and the same place where soil samples were taken. A questionnaire was developed based on the soil quality survey proposed by Garlynd et al. (1994). The questionnaire was used as an interview guide, in which the questions were structured in a way that was understood easily by the farmers. The questionnaire guide was pre-tested and corrected to be sure the research objectives were satisfied.

The survey included 42 farmers chosen at random from the tea enterprise community. Only heads of household who were experienced in tea cultivation with at least 15 years working in tea farms were interviewed. These heads of household had some types of formal education, with approximately 43% having completed a high school level education, 47% at a secondary school level, and only10% at a primary school level. Household heads were selected to interview because they were the person responsible in making decisions regarding farm practices.

Table 1. Measurement of soil quality indicators for difference of depth-weighted means among the forested, 10-, 25 and 40-yr old tea plantations.

Soil properties	Depth (cm)[b]	Forest (n=4)	10-yr (n=3)	25-yr (n=4)	40-yr (n=6)	Sig. level[a]
Soil chemical indicators						
Total C (mg g^{-1})	0-40	16.3	13.2	13.1	12.0	***
Total N (mg g^{-1})	0-40	1.4	1.1	1.0	1.0	**
Total P (µg g^{-1})	0-10	245	343	354	357	**
Total K (mg g^{-1})	0-40	15.1	12.2	13.2	10.3	**
Total S (mg g^{-1})	0-40	0.4	0.8	0.5	0.4	*
Avail. P (µg g^{-1})	0-20	5.5	21.8	12.0	6.0	**
Avail. K (µg g^{-1})	0-40	39.2	63.1	51.6	24.6	***
Soil pH	0-40	4.2	3.9	3.9	4.1	***
ECEC	0-40	4.8	5.2	5.7	5.1	ns
Fe oxides (%)	0-40	4.4	4.0	4.7	4.8	ns
Al oxides (%)	0-40	0.8	0.7	0.9	0.9	ns
Total Cd (µg g^{-1})	0-10	0.1	NA[c]	0.1	0.1	ns
Soil physical indicators						
Resistance (MPa)	0-30	4.0	3.9	4.4	4.6	***
Bulk den. (Mg m^{-3})	0-20	1.1	1.2	1.3	1.3	***
Porosity (%)	0-20	60.0	55.0	53.0	51	***
PAWC (% Vol.)	0-20	13.5	13.3	10.3	9.4	***
MWD	0-20	4.5	2.9	3.5	3.4	*
Clay content (%)	0-20	46.0	45.0	47.0	46.0	ns
Bio-indicators						
Earthworms per m^2	0-20	11.8	4.5	2.4	2.5	***

[a] Significant at 0.05 (*), 0.01 (**) and 0.001 (***) level of probability; ns = not significant. [b] Reported values are the weight-averages for the composite 0 to 10, 10 to 20 and 20 to 40 cm depth intervals for soil chemical properties; and the 0 to 10 and 10 to 20 cm depth intervals for physical properties. [c] is no available.

RESULTS

Quantitative soil quality indicators

Sensitivity analysis

Potential soil quality indicators assessed in this study included a variety of soil chemical, physical and biological properties. To be useful as an indicator of soil quality, variations in soil properties associated with management practice must be distinguishable from those associated with natural soil variability (Boehm, 1995). In our study, the soils were similar in terms of parent material, topography, and native vegetation; but varied in terms of management practice and intensity (duration).

The depth-weighted means for soil quality indicators assessed in this study are presented in Table 1. Significant differences between means were identified using the F-test. For our purposes, a given soil property was considered to be a sensitive indicator of soil quality if the probability of a greater F-value (P>F) was ≤ 0.05. Moreover, the smaller the probability value, the greater the sensitivity of the indicator variable. Conversely, a given soil property was considered to be a poor indicator of soil quality if the probability of a greater F-value was >0.05.

The most sensitive soil quality indicators ($P \leq 0.001$) were total organic C, available K, pH, mechanical resistance, bulk density, total porosity, PWAC and earthworm population. Moderately sensitive indicators ($0.001 < P \leq 0.01$) include available P and total N, P, and K. Weaker indicators of soil quality ($0.01 < P \leq 0.05$) include total S and the MWD of soil aggregates. Soil properties such as ECEC (Effective Cation Exchange Capacity), Fe and Al oxide content, total Cd, and soil texture exhibited little change with cultivation history and, consequently, were of

Table 2. Statistical levels (P>F) for contrasts among the study soils.

Property[1]	Effective depth (cm)	Forest vs. 10-yr	10-yr vs. 25-yr	25-yr vs. 40-yr
Chemical indicators				
Total C (mg g^{-1})	0-40	0.000	0.176	0.006
Total N (mg g^{-1})	0-40	0.004	0.097	0.368
Total P (µg g^{-1})	0-10	0.000	0.004	0.223
Total K (mg g^{-1})	0-40	0.000	0.055	0.040
Total S (mg g^{-1})	0-40	0.002	0.128	0.001
Avail. P (µg g^{-1})	0-20	0.000	0.000	0.000
Avail. K (µg g^{-1})	0-40	0.000	0.061	0.006
Soil pH	0-40	0.000	0.060	0.010
Physical indicators				
Resistance (MPa)	0-30	0.580	0.009	0.160
Bulk density(Mg m^{-3})	0-20	0.000	0.008	0.926
Porosity (%)	0-20	0.000	0.007	0.964
PAWC (% Vol.)	0-20	0.000	0.008	0.049
MWD (mm)	0-20	0.002	0.204	0.740
Bio-indicators				
Earthworms m^{-3}	0-20	0.000	0.003	0.604

[1] Only dynamic soil properties were selected

no value as soil quality indicators for this soil.

Effects of cultivation of soil quality indicators

To fully assess the impact of cultivation on soil quality, it is necessary to have a baseline against which cultivation induced differences can be measured (Burger and Kelting, 1998). The reference condition for this study was native forest nearby tea fields. Along with baseline comparisons, timely measures of soil quality indicators are useful in assessing soil quality responses to long-term cultivation. Soil properties within the tea enterprise (10 year, 10 to 25 year, and 25 to 40 year) were contrasted to the forest soils (Table 2). The results showing the direction of change in qualitative term (that is, ↑ = significant (*P* = 0.05) increase in population mean, ↓ = significant (*P* = 0.05) decrease in population mean, and ↔ = no significant change (*P* = 0.05) in population mean are also presented in Table 3.

In general, changes in most soil quality indicators (13 of 14) occurred relatively quickly (= 10 years) after forest clearing and cultivation (Table 2 and 3). Significant changes in soil mechanical resistance, on the other hand, did not occur until sometime between 10 and 25 years after cultivation. Not all indicators of soil quality declined following cultivation. For example, total P and S, available P and K, and bulk density increased during the first 10 years following cultivation. Thereafter, however, total S, available P and available K decreased sharply as the length of cultivation increased from 10 to 25 to 40 years. After 25 to 40 years, changes in most soil quality indicators were progressively leveled off, except total K, available P and available K, pH and PAWC.

Although the chemical, physical, and biological indicators of soil quality generally declined in response to long-term cultivation, total P, soil mechanical resistance and bulk density tended to increase with time. The increase in mechanical resistance and bulk density reflect an increase in soil compaction due to tillage operations and, like the decrease in most other soil quality indicators, are indicative of degradation in soil quality. Conversely, the increase in total-P is a result of long-term fertilizer applications and represents a management-induced enhancement of soil quality.

Qualitative soil quality indicators

Most of the farming operations involved in tea production (e.g., weeding, fertilizer application and harvesting) was carried out manually. There were no reports of labour shortages in the tea production area, indicating that farmers had performed farm works by themselves. As working in their tea production for a long time farmers know their soil indicator best. The criteria farmers used to assess changes in soil quality are defined (described) in Table 4. Farmers commonly assess soil quality in terms of tactile or visual properties of the soil, such as appearance or feel. For example, observed changes in soil color (darkness) are used by farmers to evaluate changes in organic matter content. Likewise, soil water content is assessed by feeling the soil.

Plant growth and crop yield were other criteria. Many farmers perceived that their soils were still fertile if crop

Table 3. Qualitative changes in soil quality indicators in response to tea cultivation.

Soil properties	Effective depth	Forest vs. 10- yr soils	10-yr vs. 25- yr soils	25-yr vs. 40-yr soils
Chemical indicators				
OC	0-40	↓	↔	↓
Total N	0-40	↓	↔	↔
Total P	0-10	↑	↑	↔
Total K	0-40	↓	↓	↓
Total S	0-40	↑	↔	↓
Avail. P	0-20	↑	↑	↓
Avail. K	0-40	↑	↑	↓
PH	0-40	↓	↔	↑
Physical indicators				
Soil resistance	0-30	↔	↑	↔
Bulk density	0-20	↑	↑	↔
Porosity	0-20	↓	↓	↔
PAWC	0-20	↓	↓	↓
MWD	0-20	↓	↓	↔
Bio-indicators				
Earthworms	0-20	↓	↓	↔

Table 4. Diagnostics of soil quality indicators based on farmer experiences

Indicators	Qualitative soil quality indicators used by farmers
Soil organic matter	Soil is dark-colored and feels 'good' to the touch
Soil chemical fertility	Based on yield response and observing plant growth
Soil acidity	Looking for the presence of selected weed species in the field
Soil compaction	Soil feels 'hard' when ploughing or hoeing
Soil moisture	Soil feels moist to the touch, observing the leaves at noon and evening.
Surface (A horizon) thickness	Observing the depth of dark colored soil when ploughing or hoeing.
Soil erosion	Observing the surface after rain; comparing year-to-year variations in topsoil depth when ploughing at upper and lower slope positions.
Soil structure	Observing soil when ploughing or hoeing.
Earthworm population	Observing earthworm casts at the surface in the morning or after rain.
Weed incidence	Observing evidence of weed species and communities in the field.

yields were comparable to those achieved in previous years with the same management level. In this study, crop yields from the 10 and 25 year old tea plantations (3.06 and 3.02 Mg ha^{-1} $year^{-1}$, respectively) were significantly greater than those from the 40 year old plantations (2.30 Mg ha^{-1} $year^{-1}$). Farmers considered that drop in productivity following long-term cultivation could be attributed to degradation of the soil quality. This is because the yield potential of the tea plants remained good even after 40 years of cultivation, provided an adequate supply of plant available nutrients was maintained through fertilization.

The occurrence of some wild plant species in the tea fields was a useful indicator of some soil properties. Experienced farmers linked the presence of certain weed species (e.g., *Medimilla spirei* Guill., *Melastoma candidum* D. Don and *Eupatorium odoratum* L.) to increased acidity. Likewise, species such as C*hrysopogon aciculatus* Retz., were used as indicators of poor nutrient status (soil fertility) and dryness of the soil, both of which are indicators of soil degradation. However, the use of wild plant indicator to judge soil acidity may have some limitation where as occurrence of some species (e.g. *E. odoratum* L) may be due to not only soil acidity, but also the changes of other soil properties (that is, soil moisture and soil fertility) and/or the changes of tea plants' canopy with time.

Farmers were asked to comment on ten indicators of

Table 5. Farmer perceptions of the change in soil properties with tea cultivation (expressed as a percent of 42 respondents)

Indicators	No change	Increase	Decrease	No idea
Soil organic matter	12	33	55	0
Soil chemical fertility	17	29	52	2
Soil acidity	14	38	14	34
Soil compaction	29	57	12	2
Moisture in dry season	21	10	69	0
Topsoil thickness	31	12	48	9
Soil erosion	21	36	43	0
Soil structure	31	14	55	0
Earthworm numbers	7	7	86	0
Weed incidence	19	19	62	0

Table 6. Importance of the soil quality indicators based upon the farmers' perceptions.

Indicators	Total soil quality points[1]	Overall Rank
Soil organic matter	92	1
Soil fertility	109	2
Soil compaction	145	3
Soil structure	181	4
Moisture in dry season	191	5
Earthworm numbers	254	6
Soil erosion	288	7
Soil acidity	291	8
Topsoil thickness	302	9
Weed incidence	344	10

[1] Each farmer ranked the soil quality indicators on a scale from 1 to 10, with 1 being the most important indicator and 10 being the least important. Soil quality points for each indicator were then totaled, and an overall ranking assigned to each soil variable.

soil quality (Table 5). Most recognized that organic matter content, soil fertility, soil moisture storage, soil structure, earthworm population, and weed incidence decreased over time, while soil compaction increased as a result of long-term cultivation. It is apparent that these soil indicators were well recognized and easily assessed by farmers. Farmers' assessments of these indicators were generally good agreement with soil analysis approach.

In contrast, changes of other soil indicators such as acidity (pH), thickness of topsoil, and soil erosion were not well recognized by many farmers and their answers varied from farmer to farmer (e.g. 36% of interviewed farmers indicated that soil erosion increased a long with time of cultivation, while 43% considered soil erosion decreased). The response of many farmers about changes of these soil quality indicators did not agree with results from soil analysis approach. This is possibly because that these soil indicators were not easily recognized by observation, and the criteria used to assess changes of these soil quality indicators were too complicated and unsuitable with farmers' knowledge. This may be a limitation of of farmer approach to evaluate soil quality.

Each farmer was asked to rank the relative importance of the various soil quality indicators to tea yield. Soil organic matter content, soil fertility and compaction were the most important indicators identified. Soil erosion, acidity, topsoil thickness, and weed incidence were considered to be the least important (Table 6).

Synthesis and discussion

Soil quality indicators identified by the quantitative approach as being important to long-term tea production include chemical, physical and biological soil properties. The indicators most sensitive to cultivation-induced changes were soil organic-C, nutrient supply (N, P, K, and S), pH, mechanical resistance, bulk density, total porosity, plant available water content (PAWC), the MWD of soil aggregates, and earthworm populations. There is a gradual degradation of inherent soil fertility as the "nutrient surplus" (that is, the supply of readily available nutrients present when soil was first broken and cropped) (van Kooten

1993) is depleted. Depletion of the soil nutrients, particularly available P and K, due to continued cultivation with imbalanced fertilization caused a degradation of soil quality.

Earthworms are quite vulnerable to perturbations (both chemical and physical) in the soil environment (Linden et al., 1994), and thus provide a sensitive indicator of changing soil quality. The identification of soil physical properties such as PAWC as a key soil quality indicator is a reflection of a fact that the water holding capacity was reduced following long-term cultivation. This was attributed to a lower organic-C and total porosity in the soils due to cultivation-induced changes (Topp et al., 1997). Bulk density and mechanical resistance were sensitive soil quality indicators of soil compaction (Chen, 1999). The bulk density in the surface layer of soils from 40 year enterprises was less than the critical value reported for many crops (Jones, 1983). However, soils in the northern mountainous zone are predominantly clayey so the increase in bulk density associated with long-term tea cultivation can be expected to reduce the total pore volume of the soil and have a significant effect on pore size distribution (reducing the number of both large- and medium-diameter pores and increasing the number of micropores). Such changes would restrict oxygen movement in the root zone and reduce the amount of plant available water in the soils. With respect to soil resistance, Ehlers et al. (1983) reported that at soil resistance values greater than about 4.6 MPa (similar to resistance encountered at the 40 year old tea plantations), the roots of several crops (e.g. pea, cotton, corn and oats) were adversely affected by soil compaction. However, impacts of soil compaction on crop growth depend on plant species and soil environment. Likewise, MWD of soil aggregates was also sensitive to cultivation and was identified as an indicator of soil quality for tea cultivation.

Contrast analysis of soil properties between the forest soils and those cropped for different intervals provided a measure of temporal response for the soil quality indicators. Although the largest changes in many of the soil properties occurred during the first 10 year of tea cultivation, measurable (significant) changes in key soil quality indicators were observed consistently in the older plantations. Trends associated with the various soil parameters suggested that, under current management pactices, long-term tea cultivation results in a loss of soil quality.

Along with soil analysis, qualitative indicators were identified through farmer interviews. Farm families generally work and live on their land for generations, resulting in an accumulated knowledge of how the land has changed since crop production began. Consequently, any effort to implement new soil conservation programs requires a good understanding of the indigenous knowledge of the farmer (Douglas, 1990; McCallister and Nowak, 1999). In this study, farmers identified organic matter, inherent fertility, and compaction as the most important soil quality indicators. Consequently, soil conservation programs targeted at tea growers should address these factors.

Once may doubt that if the soil changes demonstrated between 40, 25, 10 year old tea and remnant forest were entirely due to cultivation and if farmers can judge soil quality adequately as the results from this research, they may use their knowledge to choose the best soils for their 40 years ago, and again 15 or 30 years later they may make preferential choices. This is a question, "why did farmers not cultivate tea in the soil actually under remnant forest after 15 or 30 years". This is because tea is a perennial crop and after replanting at least 4 to 5 years farmers may have the first harvest. This is not economical if planting period for tea crop is short after 15 to 30 years of cultivation. The best way is to extend time of tea crop in the field by conserving soil quality.

The good agreement between farmer-based or observational (qualitative) approaches for identifying soil quality and the quantitative approach based on soil analyses confirms that using both assessment methods provide important information. Qualitative and quantitative assessment methods can both be effective diagnostic tools and both should be used for evaluating soil quality, crop productivity, and long-term sustainability of tea enterprises.

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