



# Cultivation-driven Soil Degradation in Rice Based Systems in Nalbari District, Assam: RSQI Thresholds for Sustainable Yield Maintenance

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## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

## Article Information

DOI: <https://doi.org/10.9734/ijpss/2025/v37i75556>

## Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://pr.sdiarticle5.com/review-history/138601>

Original Research Article

Received: 24/04/2025

Accepted: 27/06/2025

Published: 01/07/2025

## ABSTRACT

**Aims:** The present investigation was carried out to assess Relative Soil Quality Index (RSQI) for grouping of soils of two land use system viz. rice-fallow and rice-oilseed as good, medium and poor categories.

**Place and Duration of Study:** Assam Agricultural University, Jorhat, Assam during 2016.

**Methodology:** Geo-referenced soil samples were collected from rice-fallow and rice oilseed (toria) cropped field continuously cultivated for last ten years. In total 60 composite soil samples were

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collected from each of cultivated and uncultivated soils of rice- fallow system and 63 composite soil samples were collected from each of cultivated and uncultivated soils of rice- oilseed cropping system and from adjacent uncultivated soils in Nalbari district of Assam. The soils of the study area belong to the orders Inceptisols and Entisols. The sampling was done using core sampler and focused on the plough layer (0-15cm) and analyzed for selected physical, chemical and biological properties of soils following standard procedures. Soil management practices and crop yield data were recorded from identified farmers. The RSQI based on 14 soil parameters (Water Holding Capacity, Soil texture, Bulk density, soil pH, CEC, OC, Available N, Available P, Available K, Available S, DTPA-Zn, Available B, Available Fe and MBC) were computed.

**Results:** Results indicated that in rice-fallow system, 100% of the soils transformed to medium categories (RSQI value 50 – 70%) whereas 43% and 57% soils remained as medium (RSQI value 50 – 70%) and good category (RSQI value >70%) respectively in adjacent uncultivated soils. In rice-oilseed crop sequence, the RSQI values exhibited that 93% and 7% soils remained as medium and good category (RSQI value>70%) respectively as compared to 29% medium category and 72% good category soils under adjacent uncultivated soils. The regression lines were drawn between RSQI and % Relative yield of rice in rice-fallow system and yield of rice –oilseed system expressed in terms of equivalent yield of rice and RSQI values obtained were above 51.8% (rice-fallow) or 51.15% (rice-oilseed) to maintain 80% crop yields.

**Conclusion:** It was evident that continuous cultivation without proper soil management practices shifted the good quality soils towards medium quality soils. The RSQI study is important in reviewing the current fertility status of the soil as it indicates either the management or activities conducted is sustainable or not. Hence proper management practices are essential to maintain optimum RSQI values to sustain soil quality and agricultural productivity for increasing farmers' income.

*Keywords: Rice-fallow; rice-oilseed; RSQI; soil degradation; soil quality; sustainable land management.*

## 1. INTRODUCTION

Soil is a non-renewable natural resource and subjected to various forces of degradation in its quality due to increasing demographic pressure, intensive land use and improper management practices. In developing country like India, a large proportion of land area shows clear evidence of advanced and continued degradation affecting countries productive resource base (Sehgal and Abrol, 1994). Therefore, sustainability of agricultural system has become a major challenging issue now a day (Minhus, 2012). Agricultural sustainability depends on maintenance of improved soil quality therefore management practices based on soil quality is essential in order to have a sustainable agricultural productivity and global food security (Rao and Lenka, 2020; Celik et al., 2021). The assessment of soil quality aims to evaluate the utility and health of soils (Yadav et al., 2023). Thus, its assessment and direction of change in quality with time is a primary indicator to ensure sustainable agriculture (Karnel et al., 1997; Mastro et al., 2007). Soil quality concepts are commonly used to evaluate sustainable land management in agro ecosystem (Carter, 2000). Hence assessment of soil health has attracted a

great deal of attention in recent years because of growing public interest in determining the effects of soil management practices on physical, chemical and biological soil properties and consequently on the soil quality relative to soil sustainability (Yao et al., 2013; Schoenholtz et al., 2000). The emphasis on sustainable agriculture and more generally on sustainable land use initiated the development of soil quality concept. Soil Quality essentially means the continued capacity of soil to function as a vital living system within ecosystem boundaries to sustain biological productivity (Doran and Parkin, 1994; Karnel et al., 1997). The soil quality is a dynamic interaction between various physical, chemical and biological soil properties and can be assessed using those physical, chemical and biological properties (Dengiz, 2020). Soil quality is considered as a key element of sustainable agriculture because it is essential to support and sustain crop production and helps to maintain other natural resources such as water, air and wildlife habitat. Soil quality indices are a way to incorporate multiple points of information into one tool that can be used for decision making. It would appear to be an ideal indicator of sustainable land management and helps to access the change in dynamic soil properties.

Proper soil management practices like balanced use of chemical fertilizers, use of organic manures, incorporation of crop residues in soil and inclusion of legume crops in crop sequence etc. helps to sustain soil health and crop productivity. Conservation agricultural practices such as straw return in soil can be a good practice for improvement of soil properties and agricultural sustainability (Song et al., 2024; Shi et al., 2022). The present experiment was designed with the objective to assess the Relative Soil Quality Index (RSQI) under long term land use system viz. rice-fallow and of rice – oilseed system of Nalbari district of Assam.

## 2. MATERIALS AND METHODS

### 2.1 Collection of Soil Samples

Geo reference (N: 26°31.882' to 26° 18.224' and E: 091°30.536' to 091° 15.750') soil samples were collected from rice-fallow and rice-oilseed cropping system after harvest of rice for rice-fallow system and after harvest of second crop (toria) in rice-oilseed cropping system followed in seven blocks covering 23 villages of Nalbari district of Assam.

For comparison the soil samples from adjacent uncultivated sites were collected. The soils of the study area belong to the orders Inceptisols and Entisols and comes under AESR15.2 Q8B8 and 16.1C10A9 characterized by alluvial derived and tarai soils respectively. The sampling was done using core sampler and focused on the plough layer (0-15cm) because this is where most soil quality changes are expected to occur due to long term land use and soil management practices. Four soil samples from each unit were collected randomly and mixed to form a single composite sample, which was again divided into two parts for analysis of soil physical, chemical and biological parameters. The samples for analysis of biological properties were kept at 4°C in poly pouch after collection. Tube core sampler was used separately for collection of soil sample for determination of bulk density. At the time of collection of soil samples, the crop history including management practices was recorded from respective farmers. In total 60 composite soil samples were collected from each of cultivated and uncultivated soils of rice- fallow system and 63 composite soil samples were collected from each of cultivated and uncultivated soils of rice- oilseed cropping system covering total area of 30 hectares. Analysis of physical, chemical and biological properties was done using standard procedures.

## 2.2 Analysis of Physical, Chemical and Biological Properties of Soils

### 2.2.1 Physical properties

Physical properties viz. Bulk Density (BD), soil moisture content, soil texture and water holding capacity (WHC) were analyzed. For determination of bulk density undisturbed soil samples were collected from the field in natural condition using a tube core sampler (5.2cm diameter and 9cm length) following the standard method (Black & Hartge, 1986). The soil moisture content (MC) was determined using the gravimetric method for field moist soils by drying at 105°C for 24 hours (Gardner, 1986). The texture of the soil samples was determined by International Pipette Method (ISSS, 1929). Maximum water holding capacity in percentage was determined by using Keen Rackzowski Box described by Baruah and Barthakur (1997).

### 2.2.2 Chemical properties

The chemical properties such as, soil pH, electrical conductivity, organic carbon, CEC, available N, P, K, exchangeable Ca and Mg, available S, micronutrients such as available zinc, boron and iron were estimated following standard procedures.

For determination of soil pH, soil extracts were prepared by shaking the soil in milipore water at 1:2.5(w/v) ratio and measured using Systronic pH meter (Model  $\mu$  pH system 362) at 25°C. The soil suspension used for estimation of pH was allowed to stand for 24 h and electrical conductivity (EC) of the supernatant was measured with Conductivity Bridge (model Elico solubridge type CM-64) at 25°C.

Rapid titration procedure of Walkley and Black (1934) was followed for the determination of organic carbon (OC) content of the soil.

Cation exchange capacity (CEC) was determined following neutral normal ammonium acetate (NH<sub>4</sub>OAC) leaching method (Jackson, 1973).

The available N of the soil samples were determined by alkaline potassium permanganate method (Subbiha and Asija, 1956) as described by Jackson (1973).

The available P of the soil samples were determined using Bray's-I method meant for acidic soils (Bray and Kurtz, 1945).

Available K content of the soil samples was determined using neutral normal ammonium acetate method (Jackson, 1973).

Complexometric Titration Method involving EDTA was followed for determination of exchangeable calcium and exchangeable Magnesium content of soils (Jackson, 1973).

Available Sulphur was determined by Monocalcium phosphate extraction procedure (Ensminger, 1954).

Available Zn and Fe of the soil samples was determined by DTPA extraction method (Lindsay and Norvell, 1978) using atomic absorption spectrophotometer (Model Chemito AA203D).

Azomethine- H colometric method was followed for determination of available boron (Gupta, 1979).

### 2.2.3 Biological properties

Biological properties viz. enumeration of bacteria, fungi, *Azotobacter*, *Azospirillum* and Phosphate solubilizing bacteria (PSB), Microbial biomass carbon (MBC), Dehydrogenase activity (DHA), Phosphomonoesterase (PME) activity, fluorescein diacetate hydrolysis (FDA) activity, arylsulphatase (ARYL) activity, were analyzed following standard procedures. The classical serial dilution technique was used for enumeration of bacteria, fungi, *Azotobacter*, *Azospirillum* and phosphate solubilizing bacteria (PSB) from the soil by spread plate technique on appropriate media. Nutrient agar (NA) and Martin Rose Bengal (MRB) media were used for enumeration of bacteria and fungi respectively. The soil sample of 1 g was suspended in 9 ml sterile water blank followed by serial dilution up to  $10^{-5}$ . Aliquot of 10  $\mu$ l from  $10^{-3}$ ,  $10^{-4}$  and  $10^{-5}$  dilution were spread over solidified media in triplicates and plates were incubated at  $30\pm 1^{\circ}\text{C}$  for bacteria and fungi population.

For enumeration of *Azotobacter*, *Azospirillum* and PSB the media used were that of Burk's, nitrogen free bromothymol blue (NFb) and Pikovskaya's media respectively. 100  $\mu$ l aliquot of  $10^{-4}$  and  $10^{-5}$  dilutions were spread over the solidified media in triplicates and plates were incubated at  $30\pm 1^{\circ}\text{C}$  for *Azotobacter* and PSB while NFb plates were incubated at  $35\pm 1^{\circ}\text{C}$  for 3-5 days. The microbial numbers were estimated as colony forming unit per gram (cfu  $\text{g}^{-1}$ ) soil on dry weight basis and transformed to  $\log_{10}\text{cfu g}^{-1}$ .

Microbial Biomass carbon was determined by chloroform fumigation extraction technique

following the method of Vance et al., (1987). Dehydrogenase activity (DHA) was determined by the reduction of tri phenyl tetra zolium chloride (TTC) to try phenyl formazan (TPF) as described by Casida et al. (1964). Phosphomonoesterase (PME) activity was measured following the method of Tabatabai and Bremner (1969).

Fluorescein di acetate (FDA), hydrolysis activity was estimated following the method described by Adam and Duncan (2001) using a Nano Drop 1000 spectrophotometer (Thermo Fisher Scientific Country, USA). The assay for Arylsulphatase (ARYL) activity was carried out by using *p*-nitro phenyl sulphate (*p*-NPS) as substrate (Tabatabai and Bremner, 1970).

### 2.3 Statistical Analysis

For assessment of RSQI, 14 important and known physical, chemical and biological indicators with uniform weightage and scoring values were selected (Table 1). Each of the indicators was divided into four classes namely, class-I, class-II, class-III, and class-IV with an assigned mark of 4, 3, 2 and 1 respectively. The SQI was calculated using the following equation as

$$\text{SQI} = \sum W_i M_i$$

Where,  $W_i$  is the weight of the indicator and  $M_i$  is the mark of the indicator classes. Thus, summing up of all the 14 indicators provided the SQI value for a particular soil of the farmer's field. As per Table 1, the maximum value of SQI is 400 (best quality soil) and the minimum value is 100 (poor quality soil) (Wang and Gong, 1998). In order to judge the SQI (*i.e.* 400), the concept of RSQI was used as described by Karlen and Stott (1994).

$$\text{RSQI} = \frac{\text{Observed SQI of the given site}}{\text{Maximum value of SQI (i.e. 400)}} \times 100$$

### 2.4 Mean Per Cent Relative Yield Computation

The mean per cent relative yield of rice and toria crop included in the cropping sequence was computed with the following equation. The yield of toria grown after rice was expressed in terms of rice equivalent yield.

$$\text{Mean per cent relative yield} = \frac{\text{Observed rice yield of a given site}}{\text{Maximum yield among the sites}} \times 100$$

**Table 1. Soil quality indicators and their weights and classes for the evaluation of relative soil quality index (RSQI)**

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
<b>Physical indicators</b>					
1. Water holding capacity (%)	15	>30	20-30	8-20	< 8
2. Texture	5	Loam	LS/CL/SL/SiCL/SiL	C/S/SCL	Grit
3. Bulk density (Mg m <sup>-3</sup> )	5	1.3-1.4	1.2-1.3/1.4-1.5	1.1-1.2/1.5-1.6	<1.1/>1.6
<b>Chemical indicators</b>					
4. Soil pH (1:2.5)	5	6.5-7.5	6.0-6.5/7.5-8.0	5.5-6.0/8.0-8.5	<5.5/>8.5
5. CEC [ C mol (p+) kg <sup>-1</sup> ]	5	>18	18-15	15-10	<10
6. Av. N (kg ha <sup>-1</sup> )	10	>545	545-445	445-272	<272
7. Av. P (kg ha <sup>-1</sup> )	10	>56	56-40	40-22.5	<22.5
8. Av. K (kg ha <sup>-1</sup> )	5	>337	337-237	237-136	<136
9. Av. S (kg ha <sup>-1</sup> )	5	>25	15-25	10-15	<10
10. DTPA-Zn (mg kg <sup>-1</sup> )	4	>1.2	1.2-0.6	0.6-0.4	<0.4
11. Av. B (mg kg <sup>-1</sup> )	3	>1.5	0.7-1.5	0.3-0.7	<0.3
12. Av. Fe (mg kg <sup>-1</sup> )	3	>10	5.5-10	2.5-5.5	<2.5
<b>Biological indicators</b>					
13. Organic Carbon (%)	15	>1	1-0.75	0.75-0.5	<0.5
14. MBC (mg kg <sup>-1</sup> )	10	>400	400-300	300-100	<100
<b>Total</b>	<b>100</b>	<b>400</b>	<b>300</b>	<b>200</b>	<b>100</b>

## 2.5 Correlation Coefficient and Simple Linear Regression Analysis

Correlation coefficient and simple linear regression was drawn between RSQI and mean per cent relative yield, and the best fit was graphically presented as scatter diagram.

Based on RSQI value soils are classified as good (RSQI >70%), medium (RSQI 50-70%) and poor (RSQI <50%) category.

## 3. RESULTS AND DISCUSSION

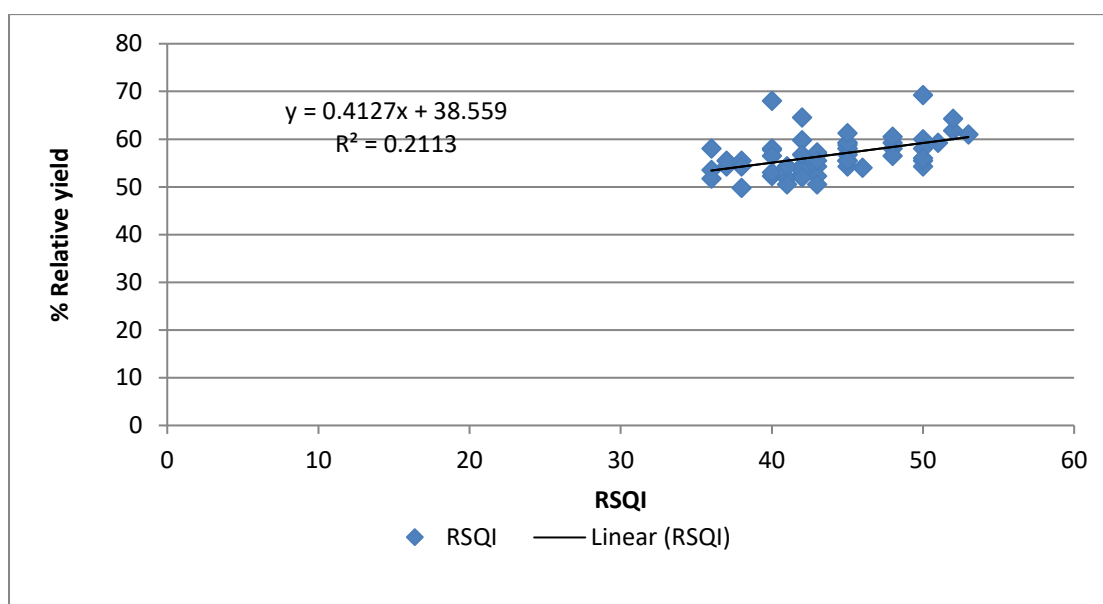
### 3.1 Computation of RSQI and Categories of Soils

The RSQI based on 14 soil indicators viz. water holding capacity (%), soil texture, bulk density ( $Mg\ m^{-3}$ ), soil pH (1:2.5), CEC [ $C\ mol\ (p+)\ kg^{-1}$ ], Av. N ( $kg\ ha^{-1}$ ), Av. P ( $kg\ ha^{-1}$ ), Av. K ( $kg\ ha^{-1}$ ), Av. S ( $kg\ ha^{-1}$ ), DTPA Zn ( $mg\ kg^{-1}$ ), Av. B ( $mg\ kg^{-1}$ ), Av. Fe ( $mg\ kg^{-1}$ ), Organic Carbon (%) and MBC ( $mg\ kg^{-1}$ ) which were known to exert significant influence on soil health were

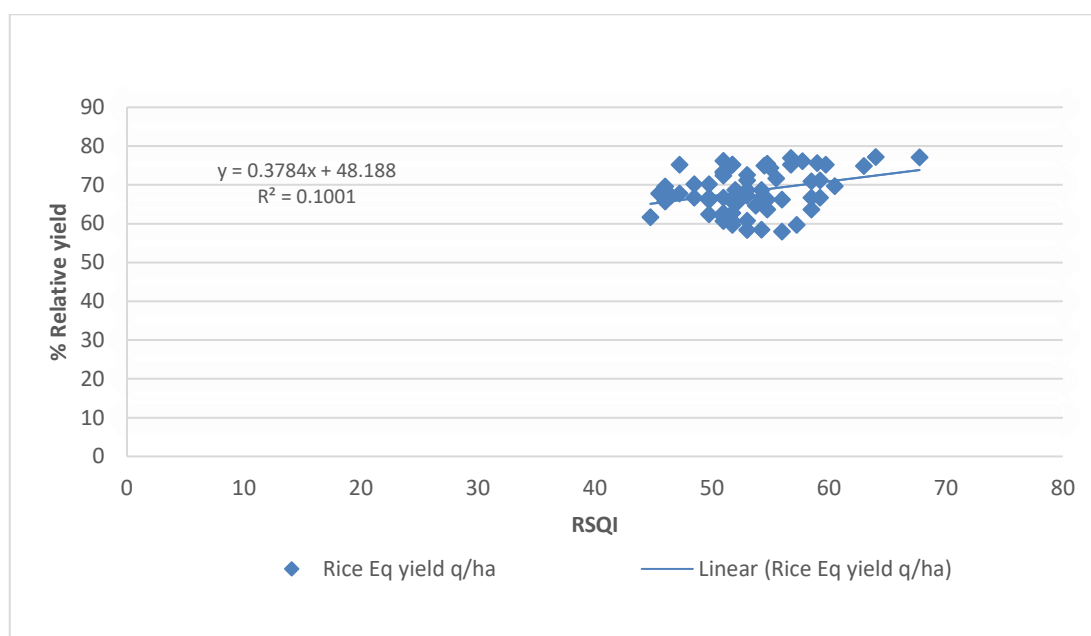
computed (Table 2). The result illustrated that in Rice- Fallow system 100% of the soils belonged to medium (RSQI-50-70%) category while in case of uncultivated soils, without poor category, 43.33% and 56.67% belonged to medium (RSQI-50-70%) and good (RSQI >70%) category correspondingly. In rice-oilseed crop sequence the RSQI value exhibited that only 6.30% soils belonged to good category (RSQI >70%) under cultivation compared to 71.43% good category (RSQI >70%) under uncultivated situation. It indicated that soil properties deteriorated in cultivated soils, might be due to inappropriate soil management practices. Similar trends of results were also observed in AESR 10.1, where majority of cultivated soils (rice-wheat, Soya bean-wheat and Soya bean-chickpea) fell under the medium (RSQI value=77.5%) and poor (RSQI value=11.20%) (Kundu et al., 2012). RSQI value computed for soil samples from rice ecosystem of Upper Brahmaputra Valley Zone of Assam indicated that majority of the soils belonged to medium category (RSQI value 58.9%) as reported by Gayan et al., (2020).

**Table 2. Grouping of soils based on Relative soil quality Index (RSQI) values for rice-fallow and rice-oilseed crop sequence**

RSQI (%)	Quality Rating	Rice-fallow system		Rice-oilseed sequence	
		Cultivated	Uncultivated	Cultivated	Uncultivated
<50	Poor	-	-		
50-70	Medium	60 (100%)	26(43.33%)	59(93.65%)	18 (28.57%)
>70	Good	-	34 (56.67%)	4 (6.34%)	45 (71.43%)
Total		60	60	63	63



**Fig. 1. Relationship between % Relative yield of rice with RSQI in rice-Fallow system**



**Fig. 2. Relationship between % Relative Yield (rice equivalent yield) of rice-toria with RSQI in rice-oilseed crop sequence**

### 3.2 Correlation Coefficient and Simple Linear Regression

The regression lines were drawn to observe the effectiveness of RSQI, and the relationship was in the form of  $y=0.4127x+38.559$  ( $R^2=0.2113$ ) in between % relative yield of rice and RSQI (Fig. 1) under rice fallow system. The regression line was used to work out the optimum value of RSQI to sustain 80% ( $4.24 \text{ t ha}^{-1}$ ) or more of the existing *infield* maximum rice yield ( $5.3 \text{ t ha}^{-1}$ ). Thus, the optimum RSQI value for attaining 80% or more of the maximum yield computed as  $\geq 51.8\%$  in the rice-fallow system (Noviyanto et al.,2017).

In rice-oilseed crop sequence, the regression line was in the form of  $Y=0.3784x +48.188$  ( $R^2=0.1001$  in between mean equivalent %RY of rice and RSQI (Fig. 2). The regression line was used to work out the optimum value of RSQI to sustain 80% ( $6.17\text{tha}^{-1}$ ) or more of the existing *infield* maximum rice equivalent yield of crops (rice and toria) ( $7.72 \text{ t ha}^{-1}$ ). Thus, the optimum RSQI value for attaining 80% or more of the maximum yield computed as  $\geq 51.15\%$  in the rice-oilseed crop sequence. Gayan et. al. (2020) from a study conducted at rice ecosystem of UBVZ (AESR 15.4) of Assam reported that the optimum RSQI value was 64.76% for attaining 80% or more rice yield and RSQI based soil functions provide information required for selection of soil management practices.

Computation of RSQI in a study conducted at coastal sandy soils of AEU-1 of Thiruvananthapuram district of Kerala showed that 60% of the soil sample fall under medium category soil class (RSQI 50-70%) and suggested more organic matter addition to improve the physical, chemical and biological constraints of coastal sandy soils (Athulya et. al., 2023). Assessment of RSQI in alluvial soils over 40 years of soil management practices through application of manure and NPK under continuous cultivation of multiple crops (jute, rice and wheat) indicated improvement of soil quality and crop yield (Singh et. al., 2017).

### 4. CONCLUSION

Agricultural land use and improper soil management practices deteriorate the soil quality over long period of time. RSQI method is suitable to know soil quality deterioration under different land use system. Moreover, RSQI study is important in reviewing the current fertility status of the soil as it will tells either the management or activities conducted is sustainable or not. Proper management practices based on RSQI values should be adopted to sustain soil health and optimize crop production in order to enhance the farmers' income.

### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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