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Impact Assessment of Tobacco Cultivation on Soil Ecosystem Using Multi-Evaluation Techniques

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Abstract

Healthy soil is the key component for growing high-quality crops and sustaining agriculture. The study was carried out to evaluate the impacts of tobacco cultivation on the soil ecosystem using soil fertility, quality, and health indices. Twenty-four (24) soil samples were collected and analyzed for important soil inherent properties, as well as soil macro- and micronutrients. The results revealed that tobacco cultivation significantly reduced soil organic matter (SOM), carbon-nitrogen ratio (C: N), total nitrogen (TN), exchangeable potassium (EK), and available copper (ACu). Soil fertility index (SFI) suggested that the decline rate of soil fertility in the tobacco field (TF) (5.84%) was lower than in the non-tobacco field (NTF) (16.33%). However, the degradation rate of soil quality index (SQI) and soil chemical health index (SHI) in TF (19.23% and 27.87%) was higher than in NTF (9.98% and 14.08%). The SHI values had a positive linear relationship (0.760) with tobacco productivity. For every degree (0.01) increase in SHI value, tobacco leaf production increased by 6.40 kg/ha, while the contribution of SHI to productivity was 57.81%. Excessive application of chemical fertilizers in TF may sustain short-term soil fertility but gradually degrade soil quality and health, disrupting the long-term productivity of the soil ecosystem.

Keywords: *Plant nutrient, plant productivity, principle compound analysis (PCA), soil fertility, soil quality, tobacco farming*

1. Introduction

Agriculture has been the way of life of mankind since the development of civilization. Although soil is essential for life, human pressure on soil resources is getting to a critical limit. Bangladesh is an agrarian country, and most of the people (51.88%) are directly involved with the agricultural sector. In FY 2018-2019, the contribution of the agriculture sector to GDP is 12.52% (1). Among the various crops produced, tobacco is playing an increasingly important role in Bangladesh, creating employment and income opportunities for farmers and helping earn important foreign exchange for the country. Tobacco farming is comparatively more economically beneficial than other crops (2) and plays a vital role in the local economy, as well as being an important solution for hunger elimination and poverty reduction. The tobacco cultivation areas are still only 0.22% of the total land as compared to all crops in Bangladesh, and employment is less than 0.5% of agricultural employment (3). According to BBS (4), the total area under tobacco cultivation in Bangladesh in FY2021-22 was 40,634 ha and the total production was 92,327 tons. Tobacco, the 6th major cash earner but 2nd topmost exporting crop, lies in the world at the 14th position in acreage and the 12th position for production (1.3% of

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global tobacco production) in Bangladesh, which is mostly grown in Rangpur, greater Kushtia (Meherpur, Kushtia, Chuadanga), and Chattogram hill tract regions. Kushtia district positions first in tobacco cultivation (4). FY2021-22, about 11,926 ha of land were cultivated under tobacco in Kushtia (5), which was 29.58% of total tobacco cultivated land in Bangladesh.

Soil is an ecosystem that can be regulated to absorb and retain rainwater during drying to provide nutrients for plant growth, filter, and buffer potential pollutants from leaving the field, and support the growth and diversity of soil microbes to keep the ecosystem functioning properly but is non-renewable in the short-term. Plants contain more than nineteen (90) elements, however, the growth and complete development of higher green plants require only sixteen elements (6, 7). Among these sixteen elements, H is obtained from water (H_2O), whereas C and O are derived from the gas CO_2. The remaining thirteen elements, referred to as mineral nutrients, are typically classified into two groups based on the amount required: macronutrients (N, P, K, Ca, Mg, and S) and micronutrients (Fe, Zn, Cu, Mo, Mn, B, and Cl). From a physiological standpoint, they are all equally necessary, regardless of the quantity needed. Plant biomass is composed of 95% O, C, and H, with the remaining 5% being composed of all other elements. Other elements, such as Ni, Na, Co, Si, and Al, which are referred to as beneficial nutrients (8). To implement suitable nutrient management strategies for sustainable crop production, one must have an excellent understanding of soil fertility, soil quality, and soil health. Fertility is an important factor in soil productivity that is directly connected to plant nutrient loss or gain. Sustainability and productivity have become closely linked to SQI, which is the ability of the soil to function within ecosystems and land use boundaries to maintain biological productivity, maintain environmental quality, and enhance plant, animal, and human health (9, 10). A fundamental set of factors that offer numerical data regarding the soil's capacity to complete a particular job can be referred to as soil health. According to Manisha et al. (10), it assists in evaluating the general state of the soil as well as the management response or resilience to anthropogenic and natural influences. Agricultural sustainability and environmental quality are determined by soil health and quality (11) as well as a crucial element in deciding whether human civilization succeeds or fails (12).

Farmers have been cultivating their land and managing their soil and fertilizers in traditional interactions with their neighbors for a long time, with a lack of agricultural extension services. To become self-sufficient, unscientific agriculture has intensified, harming the land and hastening its deterioration (12, 13). Different types of vegetation have also significantly changed the soil's chemical, biological, and physical characteristics (14). In our nation, tobacco is an alien species that has a negative ecological and environmental impact on the habitats (3). They destroy an agro-ecological system by forcing out other farmed crops that are fundamental to a community's subsistence (15). Compared to other crops, tobacco plants take up more nutrients from the soil and use them up quickly, making such soils unsuitable for healthy plant growth for the subsequent crop (16). Geist (17), also claimed that the higher agrochemical requirements of tobacco plants can harm soil health. Agrochemicals contribute greatly to the reduction of soil quality and soil health, destroy soil microbial communities, and suppress soil enzymatic activity (18). Martin-Sanz et al. (19), in Spain, and Uthappa et al. (12), in India, used the soil quality indexing technique in agroforestry ecosystems to compare the efficiency of different methods of *SQI*. Whereas *SFI* and *SQI* were practised by Abdu et al. (9) in agro-ecosystems in Ethiopia. Supriadi et al. (20) and Hermiento et al. (21) applied the *SQI* and tobacco productivity tools in Indonesian tobacco fields, respectively. No researcher in the world, including Bangladesh, has evaluated soil fertility, productivity, quality, and soil health together. Furthermore, no one has yet evaluated the impact of tobacco cultivation on the soil ecosystem compared to non-tobacco crops by analyzing soil before and after the cropping season. However, this study aimed to explore and evaluate the impacts of tobacco cultivation on soil ecosystems by comparing with NTF, assessing *SFI*, *SQI*, and *SHI*, as well as establishing relationships between *SHI* and productivity for tobacco plants. The findings of this study can help tobacco growers by suggesting balanced fertilizer applications to increase sustainable yield. Moreover, the devastating degradation of *SQI* and *SHI* resulting from tobacco cultivation will encourage policy-makers in the country to switch tobacco to other profitable crops in the future.

2. Materials and Methods

2.1. Study area

The study area, Kushtia district, has an area of 1621.15 km^2 and lies between $23^0 42'$ and $24^0 12'$ north latitude and $88^0 42'$ and $89^0 22'$ east longitude. It is a district of Khulna, an administrative division of western Bangladesh under AEZ-11 (High Ganges river floodplain). Kazihata village of Dharampur union of Bheramar upazila and Kamalpur village of Payarpur union of Daulatpur upazila of Kushtia district were selected as my research areas (Figure 1), as a large number of farmers (54.63%) in these two villages had taken up tobacco cultivation (2). A total of six TFs were randomly selected from the said two villages.

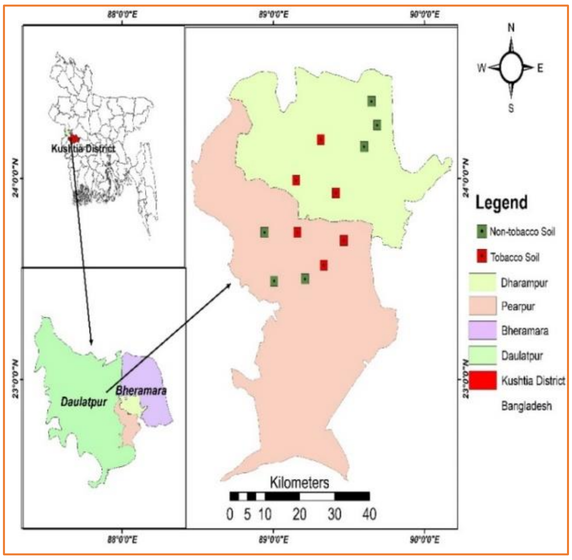


Figure 1. Location map of the study area

For a better understanding of the impacts of tobacco cultivation on the soil ecosystem, six NTFs (two rice, two wheat, and two winter maize fields) were also randomly selected from two representative villages. Rice, wheat, and maize are our staple foods, and they occupy the most cultivated land (65.47%) during the Rabi season in Bangladesh, they are contemporary competing crops with tobacco. Hence, these three crops were selected as NTF in this study.

2.2. Soil sample collection and laboratory analysis

In 2023-24, after applying fertilizer for at least three months, twenty-four (24) soil samples were collected from each representative field twice a year (before and after the cropping season). Soil samples were collected at a 0-15 cm depth at nine locations parallel to each field to generate a composite sample (3, 22-24). Approximately 500 g of soil was extracted from this composite sample and placed in marked polythene bags (7). Next, the soil was allowed to air dry at room temperature (soil moisture content up to 3%), properly crushed, passed through a 2 mm sieve and preserved for further study in airtight plastic bags. Important inherent attributes of soil (pH, EC, SOM, CEC, and ENa), as well as macro- and micronutrients (TN, AP, EK, AS, ECa, EMg, AFe, AMn, AZn, and ACu) were investigated in the laboratory. The glass electrode pH meter method (3) was applied to measure the pH of the soil (soil/water = 1:2.5 by volume); the wet oxidation (wet digestion) procedure of the Kjeldahl method was adopted to determine TN; and the wet combustion of the Walkley & Black method was utilized to determine SOM (9). A calibrated conductivity meter method was used to measure the soil EC (1:2 soil: water suspension) (25). The modified Olsen method was adopted to assess AP; the calcium dihydrogen phosphate extraction method was performed for estimating AS; and the ethylenediamine tetraacetic acid (EDTA) extraction method was employed for determining AFe, AMn, AZn, and ACu (24-25). The 1M ammonium acetate extraction method was implemented to determine ENa, EK, ECa, EMg, and CEC (24-25). Exchangeable sodium percentage (ESP) was obtained by using Eq. (1)

$$ESP = \left(\frac{ENa^{+}}{CEC}\right) \tag{1}$$

2.3. Data processing and analysis

The data received from the laboratory analysis were transferred to the master sheet and then compiled to facilitate tabulation. Data on several soil parameters were statistically analyzed using SPSS 20 and Microsoft Excel Worksheet 2016.

2.3.1. Determination of soil fertility status based on plant nutrient indexing method

The ability of the soil to provide nutrients to plants can be assessed by the soil fertility index (*SFI*) value. Based on the fertility rating chart, the nutrient availability index was computed. Soil fertility levels in the TF and NTF were evaluated using a measure designed by Parker et al. (26) and improved by Amara et al. (27-28). This study evaluated the soil fertility level adopting the SRDI-derived soil plant nutrient classification suitable to Bangladesh, as shown in Table 1 (7). The number of samples categorized as low, medium, or high, as well as the rating classes of the measured soil parameters, which were multiplied by 1, 2, and 3, were used to determine the evaluation. The soil fertility level was classified as low when the *SFI* was less than 1.67, as moderate when it was between 1.67 and 2.33, and as high when it was greater than 2.33 (9, 23, 28). The *SFI* was calculated using the following Eq. (2):

$$Soil\ Fertility\ Index\ (SFI) = \frac{(N_L \times 1)+(N_M \times 2)+(N_H \times 3)}{N_T} \tag{2}$$

The variables N_L, N_M, and N_H represent the number of samples in the low to very low, medium to optimum, and high to very high categories, respectively, while N_T was the total sample number.

Table 1. Classification of soils based on plant nutrient status

Parameters	Unit	Very Low	Low	Medium	Optimum	High	Very High	Method of Extraction
TN	(%)	≤0.090	0.091-0.180	0.181-0.270	0.271-0.360	0.361-0.450	>0.450	Kjeldahl Method
AP	(mg/kg)	≤7.500	7.510-15.000	15.100-22.500	22.510-30.000	30.100-37.500	>37.500	Modified Olsen
AS	(mg/kg)	≤7.500	7.510-15.000	15.100-22.500	22.510-30.000	30.100-37.500	>37.500	Calcium Phosphate
EK	meq/ 100g soil	≤0.090	0.091-0.180	0.181-0.270	0.271-0.360	0.361-0.450	>0.450	NH_4OAc Method
ECa		≤1.500	1.510-3.000	3.100-4.500	4.510-6.000	6.100-7.500	>7.500	NH_4OAc Method
EMg		≤0.375	0.376-0.750	0.751-1.125	1.126-1.500	1.510-1.875	>1.875	NH_4OAc Method
AFe	(mg/kg)	≤3.000	3.100-6.000	6.100-9.000	9.100-12.000	12.100-15.000	>15.000	DTPA Extraction
AMn	(mg/kg)	≤0.750	0.756-1.500	1.5100-2.250	2.256-3.000	3.100-3.750	>3.750	DTPA Extraction
AZn	(mg/kg)	≤0.450	0.451-0.900	0.910-1.350	1.351-1.800	1.810-2.250	>2.250	DTPA Extraction
ACu	(mg/kg)	≤0.150	0.151-0.300	0.310-0.450	0.451-0.600	0.610-0.750	>0.750	DTPA Extraction

Note: According to Bangladesh Agricultural Research Council (BARC), (7).

2.3.2. Determination of soil quality index (*SQI*) based on common soil parameters

Numerous techniques for evaluating soil quality have been developed, including the dynamic variation of soil quality model, multiple variable indicator kriging method, soil quality index (*SQI*) method, and soil quality card design and test kit (29). Because they are easy to use and offer quantitative flexibility, the *SQI* method is possibly the most popular approach currently in use (22, 29). This research used the *SQI* method for evaluating soil quality. Three basic procedures are involved in the process: (i) choosing relevant indicators that have already been recognized by global soil scientists; (ii) transforming indicators into scores; and (iii) combining scores into an index (30). The most important physical indicator (soil texture class), a chemical indicator (soil pH), and a biological indicator (SOC), as well as the MDS of this formula, took into account the three nutrients (N, P, and K) that are most crucial to plants. The following Eq. (3) was utilized to compute the *SQI* (31):

$$SQI = [(a \times RSTC) + (b \times RpH) + (c \times ROC) + (d \times RNPK)] \qquad (3)$$

The soil textural class ranking values were calculated by RSTC, the soil pH ranking values were determined by RpH, the soil organic carbon ranking values were determined by ROC, and the nitrogen (N), phosphorous (P), and potassium (K) ranking values were assigned by RNPK (Table 2). Furthermore, the weighted values corresponding to each of the four parameters were denoted by the values a=0.2, b=0.1, c=0.4, and d=0.3 (9).

Table 2. SQI evaluation based on assigned range values of soil parameters

Parameters (Unit)	Ranking Values					Reference
	0.2	0.4	0.6	0.8	1.0	
Soil pH	<4.0 and 8.5<	4.0-5.0	5.0-6.0	6.0-6.5 and 7.5-8.5	6.5-7.5	(30)
Textural class	clay and sand	clay loam, sandy clay, silty clay	silt and loamy sand	loam, silty loam, and sandy loam	silty clay loam, sandy clay loam	(32)
SOC (%)	≤0.58	0.58-0.99	1.00-1.99	2.00-3.20	>3.20	
TN (%)	Very Low	Low	Medium-Optimum	High	Very High	
AP (mg/kg)	Very Low	Low	Medium-Optimum	High	Very High	
AK (meq/ 100g soil)	Very Low	Low	Medium-Optimum	High	Very High	
SQI Class	<0.38= Very Poor	(0.38-0.44) = Poor	(0.45-0.54) = Fair	(0.55-0.60) = Good	(0.60<) = Best	(32)

Note: Ranges of SOC, TN, AP, and EK values from very low to very high were derived following BARC (7).

2.3.3. Determination of soil chemical health index (*SHI*) based on principle component analysis (PCA) and correlation coefficient

Soil health cannot be determined by a single method, just like human health. Additionally, the PCA approach is more objective since it selects the minimum dataset (MDS) using formulae, preventing bias and data redundancy. It does this by employing a variety of statistical tools, including multiple correlation, factor, and analysis (12). In addition, every original observation for every soil parameter was incorporated into the PCA model. For this reason, the PCA technique, introduced by Andrews et al. (22) was used in this study to determine *SHI* (13). Many methods, may be applied to determine *SHI* (22). Among them, the non-linear weighted approach is the most effective assessment method for figuring out *SHI*, although it is harder to work out (12, 22, 29). On account of this, a non-linear weighted approach was used in this research. Three steps were followed to evaluate the *SHI* in this method (22): (i) selecting the minimum data set (MDS) using PCA and correlation; (ii) transforming indicators into scores; and (iii) combining the scores into an index. In this approach, each indicator was categorized as “maximum is better”, “minimum is better”, and “optimum is better”. The non-linear transformation (*NL*) employed sigmoidal curves (22). The indicator score (S_i) was calculated using the following Eq. (4):

$$S_i = \frac{a}{(1+\left(\frac{X}{X_0}\right)^b)} \tag{4}$$

Where S_{NL}= non-linear scores, "*a*" represented the highest value that the sigmoidal curve could produce (in this study, *a*= 1), x= MDS indicator's value, the mean value of this indicator across all analyzed samples was X_0 and the coefficient denoted by "-10.5" for the "maximum is better" indicators were called "*b*" and for the "minimum is better," to "10.5" (33), as well as the indicator b = 1 were taken into account when "optimal is better" became apparent (19). Observations were rated as "optimum is better" for the indication "higher is better" up to a threshold value (34).

According to BARC (7), the threshold level values of EK, ECa, EMg, TN, AP, AS, AFe, AMn, AZn, and ACu in the soil ecosystem are >0.45 meq/100g soil, >7.5 meq/100g soil, >1.875 meq/100g soil, >0.45%, >37.5 mg/kg, >37.5 mg/kg, >15.0 mg/kg, >3.75 mg/kg, >2.25 mg/kg, and >0.75 mg/kg. N has antagonistic effects with B, Cu, and K (29) but no residual effect on soil (7). Above the threshold level, P has antagonistic effects on Fe, Mn, Zn, Cu, Mo, B, and Ni; K has antagonistic effects on Mn, Mo, and B; Ca has antagonistic effects on Fe, Mn, Zn, Cu, and B; Mg has antagonistic effects on Fe, Mn, Zn, and Cu; and S has antagonistic effects on Fe and Mo (29). Micronutrients sometimes enter the soil as impurities in chemical fertilizers and produce toxicity at very low concentrations (mg/kg plant dwt., Fe>250, Mn>500, Zn>150, and Cu>20), as well as Fe has an antagonistic relation with Mn, Cu, and Zn; Mn has Fe, Cu, and Zn; Cu has N, P, and Zn; and Zn has P, Ca, Mg, and Cu (7, 25). ENa increases sodicity and blocks CEC sites and causes Ca and Mg deficiency in soil, as well as soil EC increase salinity, therefore, the lower the amount of ENa, ESP, and EC in the soil, the better for the soil and plant. SOM positively influences positively soil's physical, chemical, and biological properties. CEC is a crucial intrinsic attribute of soil that affects soil stability, nutrient availability, pH, and soil response to fertilizers (35). On account of this, the higher the SOM and CEC of the soil, the better. The optimum pH value for maximum crop production is 5.6 to 8.4 (7). The critical limit of C: N is ten (7), and according to Durlach (36), most nutrition specialists recommend a Ca: Mg ratio of 2:1. Among the analyzed parameters in this research, SOM, TN, and CEC (37) were considered as “maximum is better”; EC, ENa, and ESP ware thought about as “minimum is better” and the rest of these parameters were appraised as “optimum is better” as one of these plant nutrients has antagonistic effects on others (29). The *SHI* was calculated using the following Eq. (5):

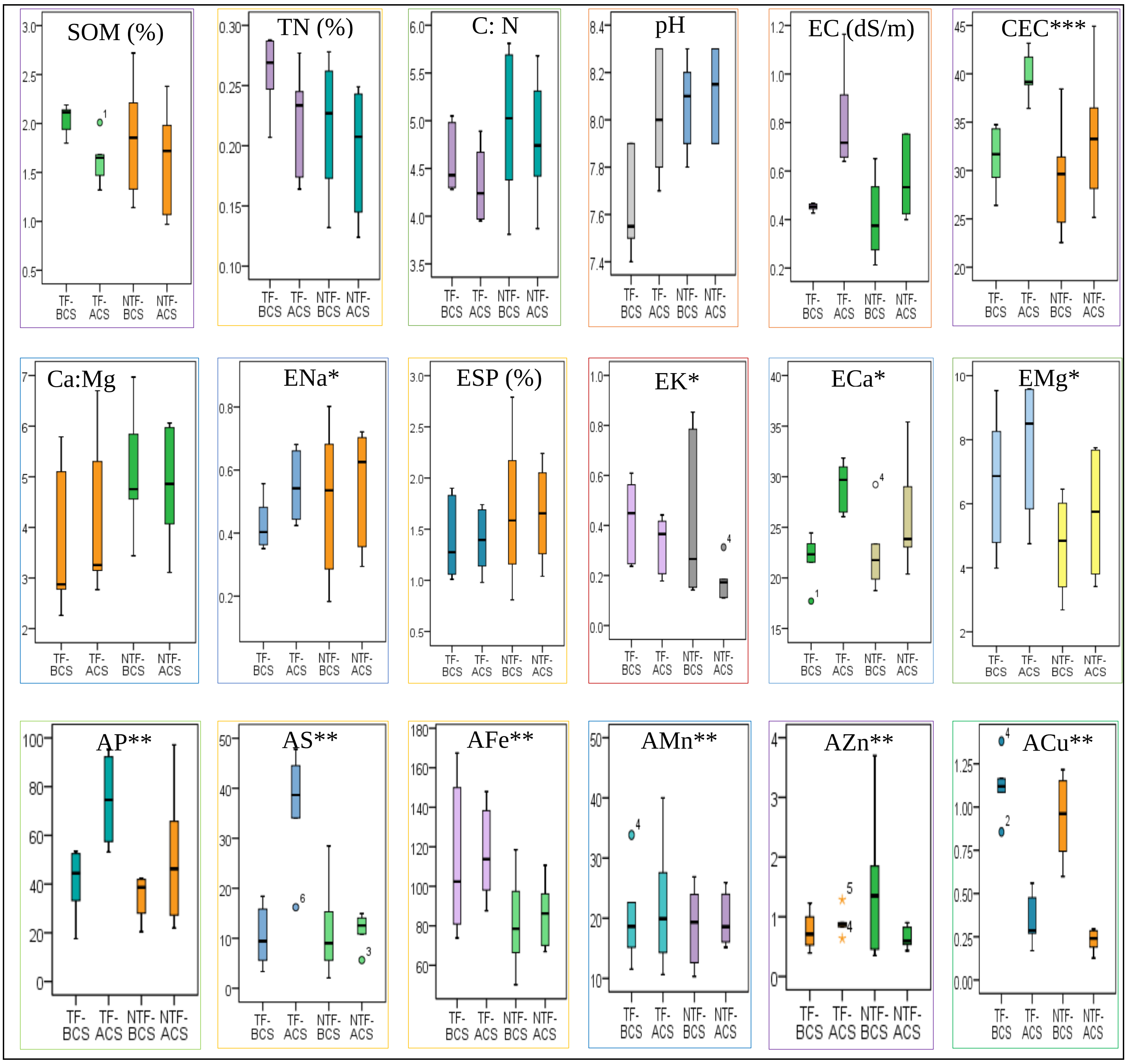
$$SHI = \sum_{i=1}^{n} W_i \times S_i \tag{5}$$

Where “n” was the number of parameters, W_i was the PC weight, S_i was the indicator score, and SHI was the soil chemical health indexing value.

3. Results and Discussion

3.1. Evaluation of effects of tobacco cultivation on soil inherent properties, soil macro, and micro plant nutrients compared to non-tobacco crop cultivation

The ability of the soil to naturally produce and actively participate in soil plant nutrients is referred to as inherent soil quality. From Figure 2, it can be found that the mean concentration of TN, AP, EK, AS, ECa, and EMg in TF-BCS soil was 0.26%, 40.95 mg/kg, 0.43 mE/100g soil, 10.34 mg/kg, 21.96 mE/100g soil, and 6.72 mE/100g soil, and the mean concentrations were 0.22%, 74.56 mg/kg, 0.33 mE/100g soil, 36.66 mg/kg, 29.12 mE/100g soil, and 7.79 mE/100g soil in TF-ACS, respectively. Considering the soil micronutrients, the average concentrations (mg/Kg) of AFe, AMn, AZn, and ACu for TF-BCS soil were 112.82, 20.08, 0.76, and 1.12 and for TF-ACS soil were 116.55, 22.07, 0.90, and 0.34, respectively. The mean SOM and C: N values decreased in TF soil from 2.05% to 1.63%, and 4.58 to 4.33, respectively. The average concentrations of pH, CEC, and Ca: Mg in TF soil were (7.63 to 8.02), (31.35 to 39.75) mE/100g soil, and (3.62 to 4.07), respectively. According to BARC (7), the average concentration of ECa, EMg, CEC, AFe, and AMn exceeded the threshold level in all samples of both TF and NTF soils, as well as C: N was below the critical level. Both in TF and NTF, soil pH was good to best (7.4-8.3), SOM (%) was low to medium (0.97-2.72), TN (%) was low to optimum (0.13-0.29), and AP (mg/kg) was medium to very high (17.55-97.18), EK (mE/100g soil) was low to very high (0.14-0.85). But EC (dS/m), ESP (exchangeable sodium percentage), and ENa (mE/100g soil) were of very good quality in both seasons of TF and NTF soils. Figure 2 demonstrates that TF soil decreased SOM (20.39%), TN (15.36%), EK (22.65%), ACu (69.51%), and C: N (5.43%) by 1.98, 1.97, 0.41, 1.10, and 1.52 times more but increased soil pH (5.02%), EC (77.39%), CEC (26.80%), AP (82.09%), ECa (32.63%), EMg (16.00%), and ENa (28.61%) by 7.67, 2.16, 2.03, 2.13, 2.06, 1.09, and 2.43 times higher compared to NTF soil, respectively. Regarding soil micronutrients, AMn and AFe of TF soil also increased by 1.91 and 0.61 times more in TF soil. AZn increased by 18.57% for TF but decreased by 57.18% for NTF soil.



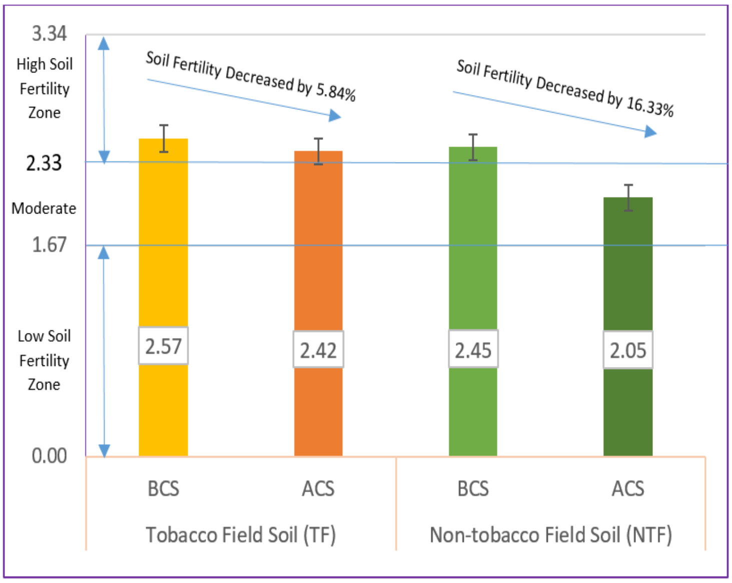
Note: * mEq/100-gram soil, **mg/kg, and ***cmol/kg, A= available, E= exchangeable. TF= tobacco field, NTF= non-tobacco field, BCS= before cropping season, ACS= after cropping season, SOM= soil organic matter, TN= total nitrogen, C: N= carbon-nitrogen ratio, EC= electrical conductivity, CEC= cation exchange capacity, Ca: Mg =calcium-magnesium ratio.

Figure 2. Box plot diagram showing soil inherent properties, soil macro, and micro plant nutrients in pre- and post-cropping seasons under TF and NTF soils.

Soil has either inherent or dynamic qualities. The key indicator of soil quality and agricultural sustainability is SOM (35). Organic fertilizers were not applied to TF or NTF soils, but tobacco is a nutrient-hungry crop compared to others, therefore, soil SOM reduction rates were slightly higher in TF than in NTF. Both the TF and NTF were heavily applied with urea fertilizers (NH_4-CO-NH_4, 46% N), but TF was higher than NTF (2). Moreover, nitrogen fertilizers have no residual effect on the soil ecosystem (7), hence the TN reduction rate for TF soil (15.36%) was slightly higher than for NTF soil (9.40%). The critical limit of C: N is 10 (ten), but after cropping, the C: N values decrease in both TF and NTF soil. The main cause of C: N loss is long-term non-application of organic fertilizers to the lands, which leads to soil degradation from bad to worse. The relative availability of the majority of inorganic nutrients and the adaptability of different plant cultivars are predicted in part by the pH of the soil. Tobacco cultivation slightly increased the pH value, this may be due to increased Na, Ca, and Mg in the tobacco soil ecosystem. Soil salinity (EC) is a basic indicator of agricultural soils, used in pedotransfer functions for soil productivity attributes. The EC value in the study area was very good (non-saline) for agriculture, but it also increased due to tobacco cultivation. This may be due to the introduction of large amounts of cations into the soil ecosystem through fertilizer application. Additional application of triple super phosphate {$Ca(H_2PO_4)_2$, TSP-20% P} and di-ammonium phosphate {$(NH_4)_2HPO_4$, DAP-20% P} increased AP in TF soil. To increase nicotine levels in tobacco leaves, tobacco companies force tobacco farmers to use sulfate of potash (K_2SO_4, SOP-42% K) fertilizer instead of muriate of potash (KCl, MOP-50% K) fertilizer. Additionally, the price of SOP fertilizer is 4 (four) times higher than MOP in Bangladesh, because of this, farmers apply SOP fertilizers in lower doses than required in tobacco fields. Moreover, the traditional practice of farmers in Bangladesh is to apply more urea and DAP fertilizers than SOP or MOP fertilizers on their farms, as a result, EK levels decreased in both TF and NTF soils. AS can be primarily supplied to TF soil by applying gypsum fertilizer ($CaSO_4.2H_2O$, 18% S), but AS can also enter the soil ecosystem through the application of SOP (17% S), magnesium sulfate ($MgSO_4.H_2O$, 12.5% S) and zinc sulfate ($ZnSO_4.H_2O$, 17.5% S) fertilizers. As a result, AS increased notably in TF soil. The soil of the study area (AEZ-11) was genetically enriched in Ca, Mg, Fe, and Mn (38). Some tobacco farmers use magnesium sulfate (9.5% Mg) fertilizer in their tobacco farms, but none use Ca-containing fertilizer. However, the application of TSP (14% Ca) and gypsum (20% Ca) fertilizers indirectly adds Ca to the soil and causes Ca-toxicity in the soil ecosystem. According to Joardar et al. (28), tobacco cultivation decreases K^+ in soil and increases Ca^{2+} content, this result well supports the research findings. Excessive application of zinc sulfate fertilizer in TF farms resulted in increased AZn. Non-application of Cu-containing fertilizer and over-application of urea, TSP, and DAP fertilizers produce dangerous levels of ACu deficiency, as Cu has antagonistic effects with N, P, Fe, Mn, and Zn (25, 29). Chemical fertilizers are known to have played a major role in the pollution of soil ecosystems (29). A sufficient but not excessive supply of plant nutrients is vital for the most effective crop yield. SOM plays a significant role in crop production and soil health by improving the soil's physical, chemical, and biological function. It influences biological activity, soil structure, water-holding capacity, nutrient contribution, and the degree of air and water infiltration (35). Nitrogen (N) is an essential plant macronutrient, as it is a key component of proteins and DNA, and is essential for plant growth, photosynthesis, and cell division (7, 24). An optimal C: N ratio (10: 1) will ensure that crops are getting what they need from the soil; when it goes too far in either direction, crop growth and yield are reduced, and soil health can be severely affected (7). Potassium (K) is a major plant macronutrient that plays important roles in cell growth, enzyme activation, water and nutrient movement, stomatal opening and closing, plant resistance, and plant quality. Potassium deficiency can cause stunted growth, reduced yield, and yellowing of leaf edges (7, 24). Copper (Cu) is an essential micronutrient for plants that plays an important role in many physiological and biochemical processes such as chlorophyll production, enzymatic activity, and pollen viability (7, 24). The depletion of SOM, C: N, TN, EK, and ACu in TF soil, may result in lower yields, lower quality leaves, lower market value, as well as poor soil quality and hinder sustainable production. From this section, it can be inferred that excess application of gypsum, DAP, and TSP and low application of MOP/SOP fertilizers, along with no manuring in TF soil cause plant nutrient imbalance and degraded soil intrinsic properties in the soil ecosystem.

3.2. Evaluation of the impact of tobacco cultivation on soil fertility

Soil fertility is the ability of the soil to support plant growth by providing essential plant nutrients. A total of ten plant nutrients (N, P, K, S, Ca, Mg, Fe, Mn, Zn, and Cu) were considered in six tobacco and six non-tobacco fields for fertility assessment. TF soil analysis results showed that for BCS, the number of low, medium, and high rating values of classified samples was 8 (13.33%), 10 (16.67%), and 42 (70.00%), and for ACS was 12 (20.00%), 11 (18.33%) and 37 (61.67%). For BCS and ACS of NTF soil, the number of low, medium, and high rating values of classified samples were 8 (13.33%), 13 (21.67%) 39 (65.00%), and 12 (20.00%), 11 (18.33%) and 37 (61.67%), respectively. Figure 3 shows that the *SFI* of BCS under TF and NTF soils was 2.57 (good soil fertility) and 2.45 (good soil fertility). However, after the harvesting season, the *SFI* of TF and NTF soils was reduced to 2.42 (good soil fertility) and 2.05 (moderate soil fertility), respectively. That is, soil fertility decreased slightly (5.84%) under TF, while soil fertility decreased significantly (16.33%) under NTF.



Note: BCS= before cropping season, ACS= after cropping season

Figure 3. Comparison of soil fertility in pre- and post-cropping seasons under TF and NTF

Tobacco is a nutrient-hungry and efficient metal-accumulating crop compared to others (39). According to BARC (7), the NPK uptake (kg/ha) of tobacco is 347, while rice, wheat, and winter maize are only 136, 238.5, and 323, respectively. So, soil fertility was expected to decrease significantly in tobacco compared to other contemporary field crops. However, the study found exactly the opposite result. The main reason for this is that tobacco cultivation is more profitable than other field crops, and a lot of money can be earned at a time (40). As a result, tobacco growers use excessive amounts of chemical fertilizers in hopes of obtaining higher yields than other existing field crops. In the Kushtia district, tobacco cultivation used a large amount of fertilizer (1592 kg/ha), which was 2.02, 2.48, and 1.48 times more than Boro rice, wheat, and winter maize cultivation (2). Except for nitrogen fertilizers, all chemical fertilizers have residual effects on the subsequent crop, *i.e.*, P fertilizers have (30-50%), k fertilizers have (20-40%), and S and Zn fertilizers have 50% (7). Thus, a large portion of this over-applied chemical fertilizer remains in the soil ecosystem. For instance, considering AP in TF, 83.33% of the samples were in the high category (N_H), and 16.67% in the medium category (N_M) during the BCS, but 100% of the samples exceeded the threshold level during the ACS, *i.e.*, fertility index values increase for TF soil. For NTF soil, there was no significant change in fertility rating during BCS and ACS. In the case of AS for TF soil, the fertility rating value increased from BCS (66.67% N_L and 33.33% N_M) to ACS (16.67% N_M and 83.33% N_H). Whereas, in NTF soil, it was reduced from BCS (66.67% N_L and 33.33% N_M) to ACS (100% N_L) (Table 1, Table 2, and Figure 2). This may be due to the residual effect of excessive application of DAP, TSP, and gypsum fertilizers in TF soil. Conversely, substantial TN, EK, and ACu reductions were observed in TF and NTF soils. This may be due to the non-application of manure and Cu-containing fertilizers, lower application of MOP/SOP fertilizers, and no residual effect of N-fertilizers. Since more fertilizer is applied to TF than NTF (2), its residual effect is also greater. Perhaps, despite tobacco being a high consumer of plant nutrients, the residual effects of over-application of chemical fertilizers such as DAP, TSP, and gypsum in TF soil, the reduction rate of *SFI* in TF soil was lower than that in NTF soil.

3.3. Evaluation of the impact of tobacco cultivation on soil quality

The sustained ability of soil to accept, store, and recycle water, nutrients, and energy. Based on the common soil parameter approach, a pre-season soil quality analysis of TF revealed that 50% of the land was of good quality, 33.33% of medium quality, and the remainder was in poor quality soil. As a result of cultivation, the soil quality of all the lands was significantly degraded, with 33.33% moderate, 50% poor, and the remainder in very poor quality soil. The pre-season soil quality analysis of non-tobacco fields showed that 16.67% was good, 33.33% moderate, 16.67% poor, and 33.33% very poor soil, but the post-harvest soil quality was 16.67% moderate, 50% poor, and 33.33% very poor quality soil. Table 3 shows that the average *SQI* value in the pre-cropping season for the soil taken from TF and NTF was 0.546 (good soil quality) and 0.451 (moderate soil quality). But in the post-cropping season, the average *SQI* value of soil taken from TF and NTF was 0.546 (poor soil quality) and 0.451 (poor soil quality), respectively. Cultivation in only one season, soil quality deteriorated significantly for both crop fields, but the rate of decline was greater in TF (19.23%) than in NTF (9.98%). Supriyadi et al. (20) worked on soils from tobacco fields in Sindoro Mountain, Indonesia, and obtained an *SQI* value of 0.57. This result is in accordance with the findings of this study. In determining soil quality, consider not only important plant nutrients (N, P, K) but also important intrinsic properties (soil texture, soil pH, and SOC) of the soil ecosystem. For this reason, significantly different results were obtained between the two indexing techniques.

Since the rate of decline in intrinsic properties was higher in TF soil than in NTF soil, the rate of soil quality degradation was also higher in TF than in NTF soil.

Table 3. Comparison of soil quality index (SQI) values based on common soil parameters

Name of Field	Collection Time	SQI		Collection Time	SQI		Comments
		Score	Class		Score	Class	
TF	BCS	0.546	Good Soil Quality	ACS	0.441	Poor Soil Quality	Soil quality deteriorated by 19.23 %
NTF	BCS	0.451	Moderate Soil Quality	ACS	0.406	Poor Soil Quality	Soil quality deteriorated by 9.98 %

Note: BCS= before cropping season, ACS= after cropping season, TF= tobacco field and NTF= non-tobacco field

3.4. Evaluation of the impact of tobacco cultivation on soil chemical health (*SHI*)

PCA, the most widely used method (19), was applied to select the minimum data set (MDS) in determining *SHI*. Soil properties showing significant variation among parameters were selected from PCA. PCs with high initial eigenvalues (≥1.0, which implies that at least 5% of the data variance was retained for indexing) represented the greatest variation (up to 81.66% from Table 4) in the dataset (22, 41). Absolute loading value within 10% of the maximum value under the same PC (9, 12) and correlation coefficients between parameters at the $t_{0.05}$ level of significance (19) were considered for MDS for each PC to avoid redundancy. PC_1, with an eigenvalue of 5.12, explained about 28.43% of the variance with a PC weight of 0.348. In this PC, three indices, namely, EMg (0.812), EK (0.805), and TN (0.726) were within 10% of the highest factor loading (Table 4) but EMg was positively correlated with EK and TN at the $t_{0.05}$ level of significance (Table 5). Therefore, only EMg was considered to represent PC_1 to avoid redundancy. PC_2 explained a variation of 21.94% with a PC weight of 0.269 and an eigenvalue of 3.95. In PC_2, three indices, namely ECa (0.768), CEC (0.721), and AP (0.720), were within 10% of the highest factor loading (Table 4), and only ECa was highly positively correlated with CEC at $t_{0.01}$ level of significance, but AP was beyond relationship at the $t_{0.05}$ level of significance (Table 5). For that reason, ECa and AP were selected from PC_2. The PC_3 explained 16.78% of the variation with an eigenvalue of 3.02 and PC weight of 0.205. In this PC, ENa had the highest factor loading (0.857), followed by ESP (0.820) (Table 4), but Table 5 shows that ENa and ESP were highly positively correlated and significant at $t_{0.01}$ level. Hence, only ENa was selected to represent from PC_3. The PC_4 had the highest factor loading of 0.463, contributed by C: N, with an eigenvalue of 1.58, a variation of 8.78%, and a PC weight of 0.107. The PC_5 described a variation of 5.75% with a PC weight of 0.070 and an eigenvalue of 1.04. This PC had the highest factor loading value, AS (0.524). Since no parameters were found within 10% of the highest factor loadings with C: N on PC_4 and AS on PC_5 (Table 4), C: N and AS were selected as MDS from PC_4 and PC_5, respectively. Using PCA analysis and a correlation matrix, out of a total of eighteen, six important parameters such as EMg, ECa, AP, ENa, C:N, and AS, and five PC weights (*Wi*) were extracted to achieve the *SHI*.

Table 4. PCA analysis of soil plant nutrients and soil inherent properties for *SHI* evaluation

Factor	Component Matrix				
	PC_1	PC_2	PC_3	PC_4	PC_5
Initial Eigenvalues	5.12	3.95	3.02	1.58	1.04
% of Variance	28.43	21.94	16.78	8.78	5.75
% Cumulative	28.43	50.36	67.14	75.91	81.66
PC Weight (W_i)	0.348	0.269	0.205	0.107	0.070
pH	-0.685	0.391	0.443	0.143	-0.183
SOM	0.431	-0.248	0.489	-0.441	0.193
TN	**0.726**	-0.239	0.000	-0.550	0.176
C: N	0.141	-0.457	0.445	**0.463**	-0.371
EC	0.276	0.664	0.360	0.338	0.266
CEC	0.497	**0.721**	0.117	-0.282	-0.296
ENa	0.413	0.049	**0.857**	-0.048	-0.108
EK	**0.805**	-0.348	-0.021	0.135	0.193
ECa	0.149	**0.768**	0.305	-0.306	-0.284
EMg	**0.812**	0.373	-0.298	-0.141	-0.213
Ca:Mg	-0.854	0.052	0.302	0.050	0.172
AP	0.104	**0.720**	-0.423	0.211	0.242
AS	0.252	0.593	0.341	0.148	**0.524**
AFe	0.672	0.210	-0.367	0.391	0.001
AMn	0.619	0.090	-0.109	0.384	-0.298
AZn	0.543	-0.279	0.245	0.379	0.082
ACu	0.309	-0.729	-0.249	-0.009	0.040
ESP	0.250	-0.347	**0.820**	0.081	0.049
Extraction Method: Principal Component Analysis					

In determining the *SQI* method, all MDS and indicator weights are preselected by world soil scientists, and the method does not consider the antagonistic effects of plant nutrients. But in *SHI* evaluation, considering the synergistic and antagonistic effects among plant nutrients, indicators showing significant differences between parameters are selected as MDS, which can prevent bias. Furthermore, the PC's weight is also calculated by the combined effect of all parameters. Because of these, the soil chemical health deterioration rate was higher than soil quality in both TF and NTF. Higher residual effects of plant macro- and micronutrients and a higher decline rate of soil inherent properties in TF soil lead to considerable degradation of soil chemical health compared to NTF. According to El-Ramady et al. (29), about 50% of the total habitable land under cultivation must be "fit and healthy" to be productive. But in just one season of cultivation, the rate of degradation of soil chemical health in TF was twice that of NTF. Agricultural practices always harm soil quality and soil health (29). Good soil health is essential for increasing productivity for a long time and for the agro-ecosystem to provide its services and benefits derived from the regulation of ecosystem processes. Manipulation of nutrient supply to increase productive output from soil conditioning through the addition of chemical fertilizers is one of the key components of agriculture. In addition, farmers only care about high crop yields and profits but often do not consider soil health or damage to the environment.

Table 5. Pearson's correlation matrix of soil plant nutrients and soil inherent properties

	pH	SOM	TN	C:N	EC	CEC	ENa	EK	ECa	AMg	Ca:Mg	AP	AS	AFe	AMn	AZn	ACu	ESP
pH	1																	
SOM	-.24	1																
TN	**-.72****	**.55****	1															
C: N	-.01	.21	-.15	1														
EC	.20	.02	-.06	-.01	1													
CEC	.05	.14	.29	-.22	**.49***	1												
ENa	.11	**.49***	.32	.36	.40	.36	1											
EK	**-.63****	.37	**.62****	.24	.02	.11	.25	1										
ECa	.39	.06	.06	-.23	**.47***	**.91****	.38	-.15	1									
AMg	**-.53****	.19	**.50***	-.13	.26	**.72****	.12	**.43***	.37	1								
Ca:Mg	**.75****	-.27	**-.58****	-.10	-.05	-.36	-.13	**-.59****	.04	**-.88****	1							
AP	.06	-.30	-.21	**-.51***	**.41***	.38	-.32	-.03	.29	**.41***	-.17	1						
AS	.09	.12	.05	-.15	**.72****	.40	.35	.09	.40	.21	-.01	.40	1					
AFe	**-.50***	-.12	.23	.03	**.41***	.35	-.02	**.51***	.04	**.67****	**-.60****	.36	.18	1				
AMn	-.34	-.08	.24	.14	.16	.27	.22	**.41***	.03	**.54****	**-.56****	.21	.13	**.49***	1			
AZn	-.21	.36	.24	.39	.13	.04	.31	**.68****	-.08	.17	-.28	-.09	.07	.29	.35	1		
ACu	**-.52****	.10	**.42***	.21	**-.44***	-.32	-0.12	**.59****	**-.47***	-.01	-.28	**-.42***	-.40	.17	.07	.36	1	
ESP	.03	**.49***	.25	**.50***	.16	-.12	**.87****	.29	-.09	-.20	-.02	**-.50***	.16	-.18	.14	.33	.08	1

**. Correlation is significant at the 0.01 level, *. Correlation is significant at the 0.05 level (2-tailed)

Hence, tobacco growers apply imbalanced chemical fertilizers on their tobacco farms, which leads to an imbalance in the soil ecosystem in terms of plant nutrient availability and ion toxicity, consequently, soil health in tobacco fields deteriorates day by day. Because of this, the tobacco field loses its productivity within 10-12 years, and then the tobacco company searches for new fields and shifts tobacco cultivation from one region to another (15).

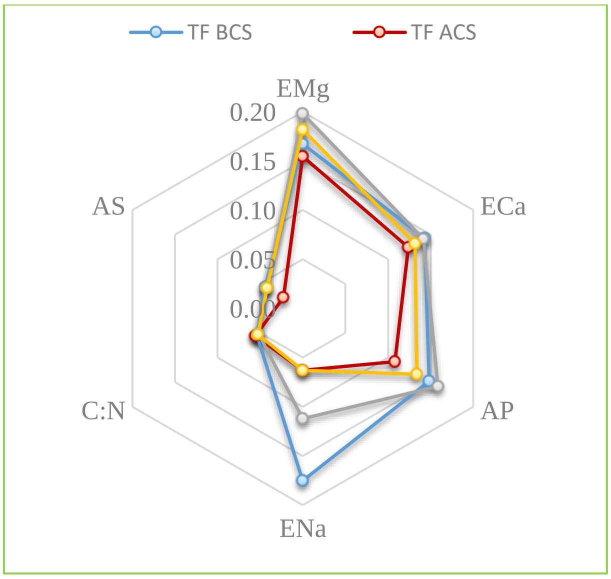


Figure 4. Radar diagram showing the contribution of MDS to *SHI* in TF and NTF soils

The radar plot (Figure 4) illustrates how much MDS soil indicators contributed to *SHI* in BCS and ACS under TF and NTF. Six parameters (EMg, ECa, AP, ENa, C: N, and AS) were selected from the PCA and correlation matrix (Table 4 and Table 5) because they showed the highest variation among the eighteen soil parameters analyzed. In BCS, some soil indicators of

MDS such as ECa, C: N, and AS contributing scores to *SHI* were more or less equal for both fields. However, in ACS, *SHI* contributing scores of C: N and AS were close to BCS for NTF, whereas the AS score in TF was reduced by 47.73%. ECa-contributing SHI scores of TF and NTF soils were significantly reduced by 13.29% and 6.38%, respectively. The reduction rate of *SHI* score caused by EMg was 7.19% for TF and 8.08% for NTF, as well as the reduction scores of *SHI* caused by ENa, which were 64.00% for TF and 43.75% for NTF soils. The rate of decrease in *SHI* score contributing to AP was higher for TF (27.03%) than NTF (15.72%).

Table 6. Comparison of soil chemical health index (*SHI*) values based on PCA and correlation

Name of Field	Collection Time	SHI		Collection Time	SHI		Comments
		Score	Class		Score	Class	
TF	BCS	0.732	Good Soil Health	ACS	0.528	Moderate Soil Health	Soil health deteriorated by 27.87 %
NTF	BCS	0.704	Good Soil Health	ACS	0.605	Good Soil Health	Soil health deteriorated by 14.08 %

Note: BCS= before cropping season, ACS= after cropping season, TF= tobacco field and NTF= non-tobacco field

Table 6 shows that *SHI* values before and after the cropping seasons in TF were 0.732 (good soil health) and 0.528 (moderate soil health), respectively. Hence, about 27.87% of soil health had deteriorated due to tobacco cultivation. But for other contemporary crops, the *SHI* value was 0.704 (good soil health) in BCS and 0.605 (good soil health) in ACS, *i.e.*, the degradation value was only 14.08%. In other words, soil erosion is increased by almost twice as much in tobacco cultivation as in other contemporary field crops. This amount of degradation occurs only through plant nutrients, without taking into account the effects of heavy metals. Uthappa et al. (12), worked with *SHI* of different tree-based land use systems in India and published the score of *SHI* as 0.737 for agroforestry and 0.556 for agro-farm. These outcomes are consistent with the research findings.

3.5. Evaluate the relationship between soil chemical health and tobacco crop productivity

A crop's optimum productivity (yield) depends on sufficient amounts of plant nutrients. Soil health affects the availability of essential plant nutrients in the soil ecosystem and subsequently the growth and productivity of crops, including tobacco. In this study, regression and correlation analysis were used to determine the extent to which soil health (independent variable) affects tobacco yield (dependent variable). The analyzed *SHI* values of the six TFs were 0.684, 0.659, 0.820, 0.731, 0.742, and 0.720 (Tables 4 and 5), as well as the tobacco leaf yield (kg/ha) of those six respective fields, which were 2285, 2324, 2396, 2384, 2401, and 2334, respectively (field survey report). The results of the regression and correlation analysis between the two variables are displayed in Figure 5. The coefficient of correlation (r) between *SHI* and tobacco productivity was high, reaching 0.760. The high and positive value of the correlation coefficient indicated that there was a strong positive relationship between *SHI* and tobacco productivity. Hence, the higher the *SHI* value, the higher the productivity of the tobacco plant. Based on the regression coefficient, every degree (0.01) increase in SHI value positively affected the productivity of 6.40 kg/ha of tobacco leaves. These results are in good accordance with the findings of (21). In addition, soil chemical health contributed 57.81% to the productivity of tobacco plants, the remaining were influenced by other factors such as crop management, soil management, and intercultural operation, as well as physical and biological properties of that soil.

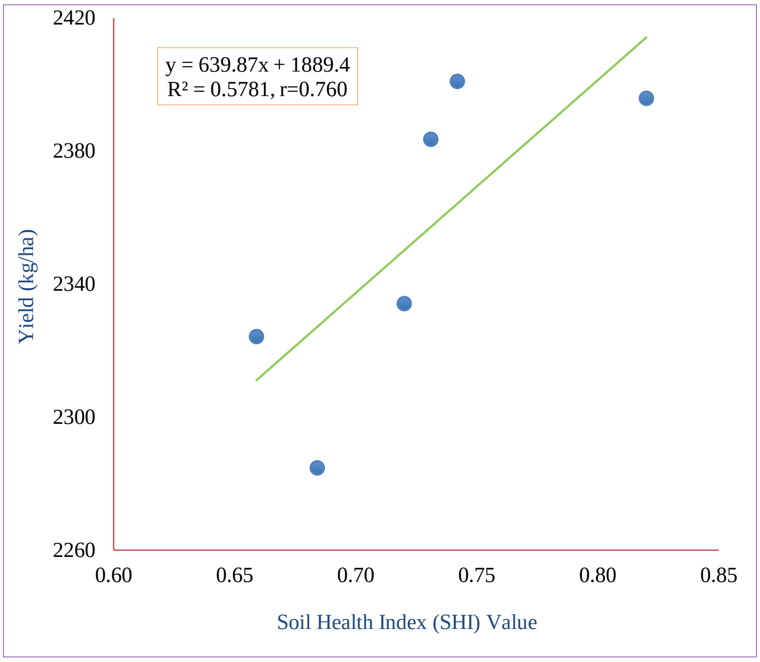


Figure 5. Regression and correlation analysis between *SHI* and tobacco crop productivity

Plant nutrient levels and transformations are essential to soil quality and soil health (28). The words soil fertility and quality are two distinct philosophical categories. Plant nutrients in soil ecosystems are controlling factors in determining soil fertility, but a key element of ecosystem health and agricultural sustainability is soil quality. Sometimes the terms "soil quality" and "soil health" are employed simultaneously. But soil health reflects a holistic approach to comprehending soil ecosystems and considers soil as a limited, short-term, non-renewable, and dynamic resource (29). Determining the soil's fertility is crucial for recent productivity in the soil ecosystem, but a deeper understanding of soil quality and soil health is extremely important for managing land use, crop productivity, and agricultural sustainability. These two factors (soil quality and soil health) provide early warning signs of unfavorable trends and a useful benchmark for assessing present and future actions (42). For this reason, in order to assess the complete impact of any crop cultivation on the soil ecosystem, it is essential to take into account these three assessment techniques, *i.e.*, soil fertility, quality, and health indexing techniques. The ultimate goal of sustainable agriculture for future generations is to maximize yield with minimal disruption to the environment. But to achieve high leaf output and quality, more nutrients, such as N, P, K, Ca, Mg, and S, are required for tobacco plants (28). To provide these nutrients, TF must apply large amounts of chemical fertilizers, which will surely cause destructive soil erosion. The chemical features of tobacco soil were solely investigated in this study; future studies can look at the chemical, physical, and biological characteristics of tobacco soil.

Conclusions

To ensure high crop yield, fertilizers are applied to the soil to compensate for nutrient deficiencies and also to increase the soil's ability to supply plants with adequate amounts of nutrients. Besides, only balanced fertilizers increase agricultural productivity without endangering ecosystems. The results of this study revealed that additional application of DAP, TSP, and gypsum fertilizers in TF soil increased soil pH (5.02%), EC (77.39%), CEC (26.80%), AP (82.09%), ECa (32.63%), EMg (16.00%), and ENa (28.61%) by 7.67, 2.16, 2.03, 2.13, 2.06, 1.09, and 2.43 times more decreased compared to NTF soil, respectively. Tobacco is a nutrient-hungry plant, along with no application of manures and MOP fertilizers, as well as the application of SOP fertilizer in low doses in TF soil dropped SOM (20.39%), TN (15.36%), EK (22.65%), ACu (69.51%), and C: N (5.43%) by 1.98, 1.97, 0.41, 1.10, and 1.52 times greater than NTF soil. The residual effects of plant macro- and micronutrients on the soil ecosystems caused a slight reduction in soil fertility (4.90%). But the decline in inherent properties in TF soil resulted in soil quality from good to poor and soil chemical health from good to moderate, i.e., significantly degraded *SQI* values (19.23%) and *SHI* values (27.87%) in TF soil compared to NTF. Six parameters out of eighteen, EMg, ECa, AP, ENa, C: N, and AS, showed the most variation in PCA analysis and facilitated the computation of *SHI*. *SHI* had a positive linear relationship (0.760) with tobacco productivity; it came to light that the production of 6.40 kg/ha of tobacco leaves was positively impacted by every degree (0.01) increase in *SHI* values. Moreover, *SHI* contributed 57.81% to the productivity of tobacco plants, and the remainder was influenced by other factors. The excessive application of chemical fertilizers in tobacco fields sustains short-term production but disrupts long-term productivity in the soil ecosystem. The results of this study will help farmers by suggesting reduced application of gypsum, DAP, and TSP fertilizers and increased application of MOP/SOP fertilizers along with manures as a balanced way to increase sustainable tobacco yield. Tobacco cultivation leads to plant nutrient imbalances, ion toxicity, damage to soil intrinsic properties, and continuous degradation of *SQI* and *SHI*, rendering the soil unproductive after a certain period. This devastating erosion of the soil ecosystem caused by tobacco farming will encourage our policymakers to diversify tobacco farmers into other profitable crops.

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Authors' contribution

Anupam Roy: Conceptualization; methodology; investigation; sample collection; sample analysis, data curation; data analysis; software computation; writing-original draft.

M. G. Mostafa: Conceptualization; methodology; investigation; project administration; validation; software; supervision; writing-review & editing.

Conflicts of Interest

The authors declare that they have no conflict of interest.

References

1. BBS. Preliminary report on population and housing census 2022. Bangladesh Bureau of Statistics, Statistics and Informatics division, Ministry of Planning, Government of the People's Republic of Bangladesh. 2022. https://www.bbs.gov.bd.
2. Roy A, Naz S, Mostafa MG. Tobacco farming and its socio-economic determinants in Kushtia district of Bangladesh. Journal of Sustainability and Environmental Management (JOSEM). 2024; 3(1):9-18.
3. Salam TB, Zaman SMS, Hossen SMT, Nur A. Consecutive 2-year data analysis to assess the soil quality and ecological risk of heavy metals in tobacco field: a case study in northern Bangladesh. SN Applied Sciences. 2021; 3:193. https://doi.org/10.1007/s42452-021-041 52-z.
4. BBS. Yearbook of Agriculture Statistics. Bangladesh Bureau of Statistics, Government of Bangladesh, Dhaka. 2022. https://www.bbs.gov.bd.
5. DAE. Yearly reports on tobacco cultivation status. Ministry of Agriculture, Department of Agriculture Extension, Khamarbari, Kushtia, Bangladesh. 2023.
6. Arnon DI, Stout PR. The essentiality of certain elements in minute quantity for plants with special reference to copper. Plant Physiology. 1939; 14:371-375.
7. BARC. Fertilizer recommendation guide-2018. Bangladesh Agricultural Research Council, Farmgate, Dhaka 1215. 2018. ISBN: 984-500-029-1.
8. FAO. Plant nutrition for food security-a guide for integrated nutrient management. Fertilizer and plant nutrition bulletin 16:1-59, Food and Agriculture Organization of the United Nations, Rome, Italy. 2006.
9. Abdu A, Laekemariam F, Gidago G, Getaneh L. Explaining the soil quality using different assessment techniques. Applied and Environmental Soil Science, 2023; 1-15. https://doi.org/10.1155/2023/6699154.
10. Manisha G, Ram AM, Ajay BM. Evaluating the soil quality of three sub-watersheds in Udayapur District, Nepal, Journal of Environmental and Soil Sciences. 2020; 5(2):614-621.
11. Pierzynski GM, Sims JT, Vance GF. Soils and environmental quality. Boca Raton, Lewis Publishers. 1994.
12. Uthappa AR, Devakumar AS, Das B, Mahajan GR, Chavan SB, Jinger D, Jha PK, Kumar P, Kokila A, Krishnamurthy R, Mounesh NV, Dhanush C, Ali I, Eldin SM, Al-Ashkar I, Elshikh MS, Fahad S. Comparative analysis of soil quality indexing techniques for various tree-based land use systems in semi-arid India. Frontiers. 2024; 1-12. https://doi.org/10.3389//ffgc.2023.1322660.
13. Biradar S, Ingle S. Soil health assessment: integrating biological, chemical and physical indicators. Advances in Soil Science. 2023; 1-27.
14. Tauqeer HM, Turan V, Farhad M, Iqbal M. Sustainable agriculture and plant production by bio-char in the era of climate change in managing plant production under changing environment. Springer. 2022; 21-42.
15. Akhter F. Tobacco cultivation and its impact on food production in Bangladesh. UBINIG. 2011; 1-11.

16. Yanda PZ. Impact of small-scale tobacco growing on the spatial and temporal distribution of miombo woodlands in western Tanzania. Journal *of* Ecology *and the Natural* Environment. 2010; 2:10-16.
17. Geist JH. Soil mining and societal responses: the case of tobacco in eastern Miombo highlands. Ashgate Publishing Ltd, Aldershot. 1999; 119-148.
18. Shun-hong H, Bing P, Zhi-hui Y, Li-yuan C, Li-cheng Z. Chromium accumulation, microorganism population and enzyme activities in soils around chromium-containing slag heap of steel alloy factory. Transactions of Nonferrous Metals Society of China. 2009; 19:241-248. https://doi.org/10.1016/S1003-6326(08)60259-9.
19. Martin-Sanz JP, Santiago-Martin AD, Valverde-Asenjo I, Quintana-Nieto JR, Gonzalez-Huecas C, Lopez-Lafuente AL. Comparison of soil quality indexes calculated by network and principal component analysis for carbonated soils under different uses. Ecological Indicators. 2022; 143:1-14. https://doi.org/ 10.1016/j.ecolin d.2022.109374.
20. Supriyadi, Sudaryanto R, Winarno J, Hartati S, Jamil IS. The quantitative soil quality assessment tobacco plant in Sindoro mountainous zone. Journal of Degraded and Mining Lands Management. 2014; 1(3):105-110. https://doi.org/10.15243/jdmlm.2014.013. 105.
21. Hermiyanto B, Winarso S, Kusumandaru W. Soil chemical properties index of tobacco plantation land in Jember district. Agriculture and Agricultural Science Procedia. 2016; 9:181-190. https://doi.org/10.1016/j. aaspro.2016.02.118.
22. Andrews SS, Karlen DL, Mitchell JP. A comparison of soil quality indexing methods for vegetable production systems in northern California. Agriculture, Ecosystems and Environment, 2002; 90:25-45.
23. Sachan HK, Krishna D. Assessment of soil fertility status using nutrient index approach in cassava farms of Rewa Province, Fiji. Indian Journal of Agricultural Research. 2021; 1-5. https://doi.org/10.18805/ IJARe.AF-680.
24. SRDI. Soil, water, plant material, and fertilizer analysis, soil fertility assessment, soil degradation and its impact on the agricultural program, Soil Research Development Institute, Farmgete, Dhaka 1215. 2012.
25. FAO. Guide to laboratory establishment for plant nutrient analysis, Fertilizer, and Plant Nutrition Bulletin 19, Food and Agriculture Organization of the United Nations, Rome, Italy. 2008.
26. Parker FW, Nelson WL, Winters E, Miles IE. The broad interpretation and application of soil test information. Agronomy Journal. 1951; 43(3):105-112.
27. Amara DMK, Patil PL, Kamara AM, Saidu DH. Assessment of soil fertility status using nutrient index approach. Academia Journal of Agricultural Research. 2017; 5(2):28-38.
28. Joardar JC, Fathema K, Basu S. Effect of tobacco cultivation on soil fertility and farmer’s profitability in the socio-economic perspective of Bangladesh. Research Square. 2022; 1-17. https://doi.org/10.21203/ rs.3.rs-1388464/v1.
29. El-Ramady HR, Alshaal TA, Amer M, Domokos-Szabolcsy E, Elhawat N, Prokisch J, Fari, M. Soil quality and plant nutrition. Sustainable Agriculture Reviews 14, Springer. 2014; 14(11):1-104. https://doi.org/10. 1007/978-3-319-06016-3_11.
30. Thapa MS, Bhattarai T, Sharma RP, Baburam K, Puri L. Analytical study on fertility status and soil quality index of Shorearobusta forest, central Nepal. Tribhuvan University Journal. 2019; 33(2): 1-14. https://doi.org/ 10.3126/tuj.v33i2.33560.

31. Tesfahunegn GB. Soil quality assessment strategies for evaluating soil degradation in northern Ethiopia. Applied Environmental Soil Science. 2014; 1-14. https://doi.org/10.1155/2014/646502.
32. Bajracharya RM, Sitaula BK, Sharma S, Jeng A. Soil quality in the Nepalese context an analytical review. International Journal of Ecology and Environmental Sciences. 2007; 33(2): 143-158.
33. Zhang C, Xue S, Liu GB, Song ZL. A comparison of soil qualities of different re-vegetation types in the loess plateau, China. Plant Soil. 2011; 347:163–178. https://doi.org/10.1007/s 11104-011-0836-5.
34. Liebig MA, Varvel G, Doran J. A simple performance-based index for assessing multiple agroecosystem functions. Agronomy Journal. 2001; 93:313–318.
35. Abdulhamid Z, Agbaji EB, Gimba CE, Agbaji AS. Physico-chemical parameters and heavy metals content of soil samples from farms in Minna. International Letters of Chemistry, Physics, and Astronomy. 2015; 58:154-163. https://doi.org/10.56431/p-12ly57.
36. Durlach J. Recommended dietary amounts of magnesium: Mg RDA. Magnesium Research. 1989; 2(3):195-203.
37. Tiessen H, Cuevas E, Chacon P. The role of organic matter in sustaining soil fertility. Nature (London). 1994; 371:783-785.
38. Shil NC, Saleque MA, Islam MR, Jahiruddin M. Soil fertility status of some of the intensive crop growing areas under major agroecological zones of Bangladesh. Bangladesh Journal of Agricultural Research. 2016; 41(4):735-757.
39. Kozak K, Antosiewicz DM. Tobacco as an efficient metal accumulator. Bio-metals. 2022; 36:351-370. https:// doi.org/10.1007/s10534-022-00431-3.
40. Srinivas A, Reddy DD, Reddy KV, Hema B, Krishna SK. Impact assessment of bidi tobacco in Gujarat. Indian Journal of Extension Education. 2022; 58(2):144-148.
41. Li X, Li H, Yang L, Ren Y. Assessment of soil quality of croplands in the corn belt of northeast China. Sustainability. 2018; 10(1):248.
42. McGrath D, Zhang CS. Spatial distribution of soil organic carbon concentrations in grassland of Ireland. Applied Geochem. 2003; 18:1629-1639.