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(RESEARCH ARTICLE)

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Eleven-year soil fertility changes in Dinogeng agricultural extension area of Kgatleng District in Botswana

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Abstract

This study was conducted in Dinogeng Agricultural Extension Area (DAEA) in the Kgatleng District located in the eastern part of Botswana. The objective of the study was to assess soil fertility changes over an eleven-year period (2009–2020) in the extension area. In the meantime, the Integrated Support Programme for Arable Agricultural Development (ISPAAD) was launched and is continuing. Soil test data of 18 arable-farming sites for the period after inception of ISPAAD in 2009 until 2020 was obtained from the Department of Agricultural Research Soil Analytical Laboratory and Ministry of Agriculture. Geographical coordinates of the ploughing fields were taken during field work using a Geographical Positioning System (GPS). Based on availability of information, soil reaction (pH), Organic carbon (OC) and Cation Exchange Capacity (CEC) of soils for the 18 arable-farming sites were compared with data acquired from National Soil Map of Botswana (1988), scale 1: 250 000. The results showed an average significant decline of 1.55 for soil pH ($P < 0.05$), 0.16 % for OC ($P < 0.01$) and 6.75 Cmol/kg for CEC ($P < 0.01$). Farming practices have however, undergone some remarkable transformation including the use of fertilizers for replacing nutrient loses. The findings from this study may be useful to guide the development of functional soil fertility management plan for Dinogeng Agricultural Extension Area.

Keywords: Dinogeng Agricultural Extension Area; ISPAAD; Soil fertility changes; Botswana.

1. Introduction

Insufficient food production is a major problem in Botswana. Government introduced Integrated Support Programme for Arable Agricultural Development (ISPAAD) subsidy programme in 2008 to support arable farmers to increase production for achievement of household and national food security. Expected outcomes from ISPAAD include improvement of farm output and productivity through enhancement of farmers' access to inputs comprising seeds, fertilizers, draught power, credit, cluster fencing, potable water and other agricultural services. The area of land planted and the number of ISPAAD beneficiaries increased when the programme was introduced but production remained low (BCA Consult., 2012). Most of the arable farmers are smallholder farmers who lack farming skills, resources and dependant on rain-fed agriculture which is vulnerable to climate change.

Many of the smallholder farmers use unsustainable management practises. Poor management practices negatively impact on the soils. The soils for smallholder farmers have been severely depleted through generations of unsuitable farming methods including ploughing, mono-cropping, little or no replenishment of nutrients and burning of residue [1]. Use of unsustainable farming techniques has led to land degradation which can be revealed by poor yields. The findings of the Desert Margin Programme indicated a deterioration of soil quality, both in terms of nutrient depletion and poor physical properties for cultivated soils in comparison to the virgin soil, as a result of continuous cultivation

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[2]. Although the impact of cultivation is known to cause soil nutrient loss worldwide, the magnitude of the change in the study area is not known. This study, therefore, investigated soil fertility changes between 2009 when ISPAAD was launched until 2020 in the Dinogeng Agricultural Extension Area (DAEA). In the meantime, the ISPAAD programme is continuing.

2. Materials and Methods

2.1. Site Description

The study was conducted in Dinogeng Agricultural Extension Area (DAEA). It extends from 24^0 8 0′ to 24^0 35 0′′ S latitude and 26^0 5 0′ to $26^0$35 0′ E longitude and it covers an area of about 83 100 ha. An overview of the boundary of the study area is given in Figure 1.

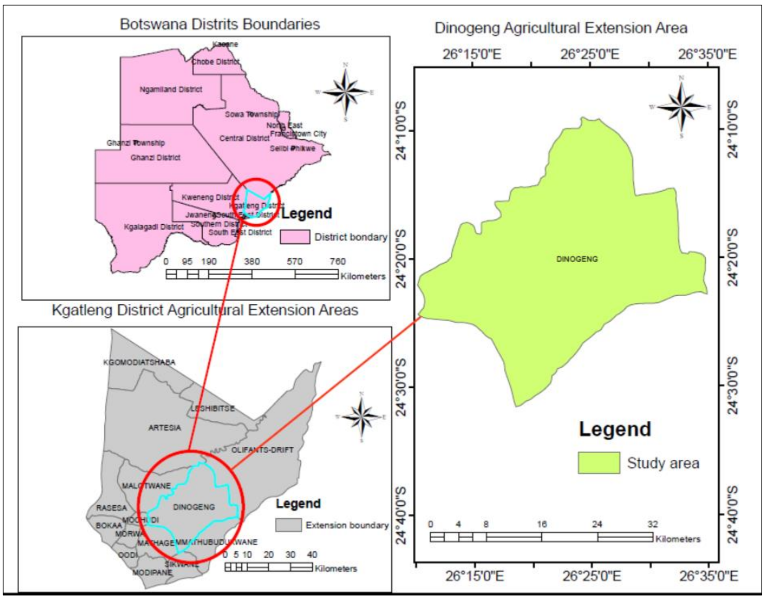

Figure 1 Location of DAEA in Botswana

2.2. Climate

The area of study is characterized by low and unreliable rainfall and very high summer temperatures. The climate is semiarid with a mean annual average temperature of 20.7 ^{0}C fluctuating from 13.2 ^{0}C to 28.2 ^{0}C (Statistics Botswana, 2016). The semi-arid climate is characterized by erratic and high intensity rainfall. The annual precipitation of DAEA is based on the estimates obtained from the records of three nearby rainfall stations. The rainfall ranges from 348 mm to 404 mm with an average of 375 mm and standard deviation of 11 mm. The area receives summer rains and the rainy season is from the beginning of October to the end of March.

2.3. Soils

The soils of DAEA are predominantly Luvisols. These types of soils are characterized by a subsurface horizon of clay accumulation (an argillic B-horizon), with a very high water retention capacity and nutrient status [3]. The Kgatleng District Council (2002) described the soils in terms of the land unit system. The Notwane plain system straddles the Notwane River and comprises of soils that are deep light textured and acidic. The dominant soils have been reported to be sandy clay loam to sandy clay [4]. The soils are relatively poor but more fertile in comparison with the sandveld in the western part of the country. The soil fertility map for the area of study is presented in Figure 2.

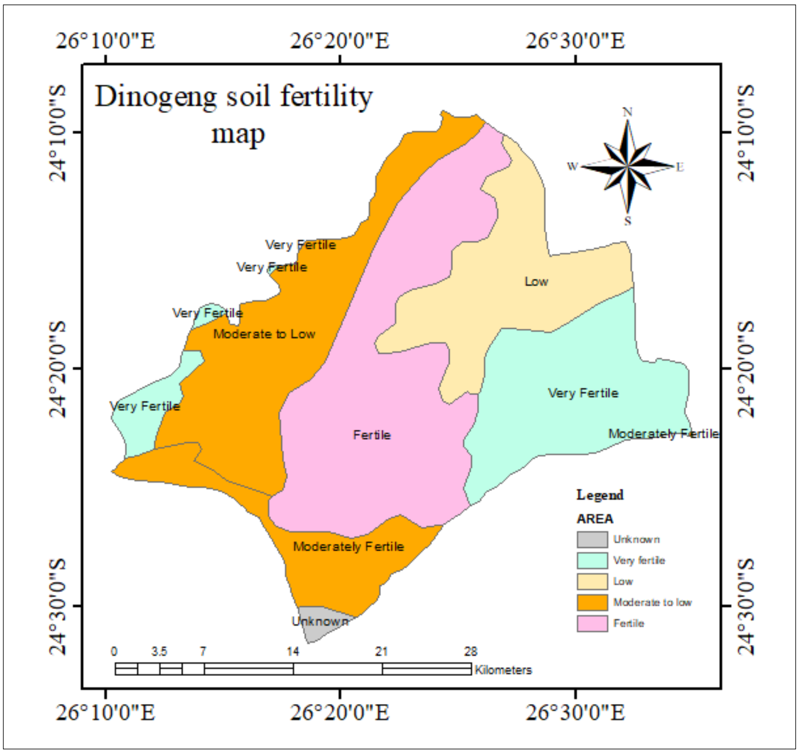

Figure 2 Soil fertility map of DAEA

The DAEA generally has flat and undulating topography with occasional rocky outcrops and several extensive drainage channel systems. The altitude of the area ranges between 901 m and 1003 m above mean sea level. There are neither hills nor permanent water bodies in the study area. The communities around DAEA depend on ground water for their livelihood. Notwane River flows from south-west to north-east.

2.4. Vegetation

The vegetation of DAEA is dominated by shrubs with areas of woodland and savanna. Almost 50% of the area is covered by shrubs; about 7% is evergreen forest mainly along the Notwane River and other drainage lines within the study area. Human related influences like unsustainable use of fuel wood and other activities, has changed the vegetation patterns considerably since the last century [5] . Climate change also contributes significantly to the existing stresses causing changes in prevalent vegetation and rangeland cover, affecting species types, composition and distribution, as well as those depending on them [6].

2.5. Assessment of soil fertility changes

Soil test data of 18 arable-farming sites for the period after inception of ISPAAD in 2009 until 2020 were obtained from the Department of Agricultural Research Soil Analytical Laboratory, Agricultural Extension Officers and the Agricultural District Headquarters at Mochudi. The following soil chemical properties were considered for assessment of soil fertility based on availability of information: soil pH, Organic carbon (OC) and Cation Exchange Capacity (CEC). The analytical soil test report comprised of pH, Organic Carbon (OC), Phosphorus (P), Calcium (Ca), Magnesium (Mg), Potassium (K), and Sodium (Na). Cation exchange capacity test data was available between 2009 and 2014. The CEC test data for 2015 – 2020 was determined through summation of the cations. Geographical coordinates of arable-farming sites were taken during field work using a GPS.

Baseline data for the 18 arable-farming sites was extracted from the National Soil Map of scale 1: 250 000 for comparison purposes. The average CEC and pH data were obtained from the soil map made available by the Soil Mapping Section of the Ministry of Agriculture. Interpretation of the information was done with the use of the Revised General Soil Legend of Botswana [7] and Harmonized World Soil Database [8]. The OC information was gathered from Soil Mapping and Advisory Service Project of the FAO/UNDP [9]. The OC information was then used to estimate soil organic matter (SOM) content using the equation SOM (%) = OC (%) x 1.72 [10]. The soil test results during ISPAAD were then compared to the baseline data and a test for statistical significance was performed for the three soil parameters.

2.6. Statistical Analysis

The hypothesis test was used to determine whether a claim about the soil parameters was true or not [11, 12]. Raw data mean and standard deviation for the three soil parameters were entered into One Sample t-test Calculator to obtain the t-score test statistic and the p-values associated with it. The p-value for one tail test was then compared with pre-determined values such as 0.10, 0.05 or 0.01 to reject the null hypothesis and conclude that the findings are statistically significant or accept the alternative hypothesis.

3. Results and Discussion

3.1. Baseline Data

Figure 3 shows locations of the ploughing fields in the study area whereas the primary soil characteristics are given in Table 1.

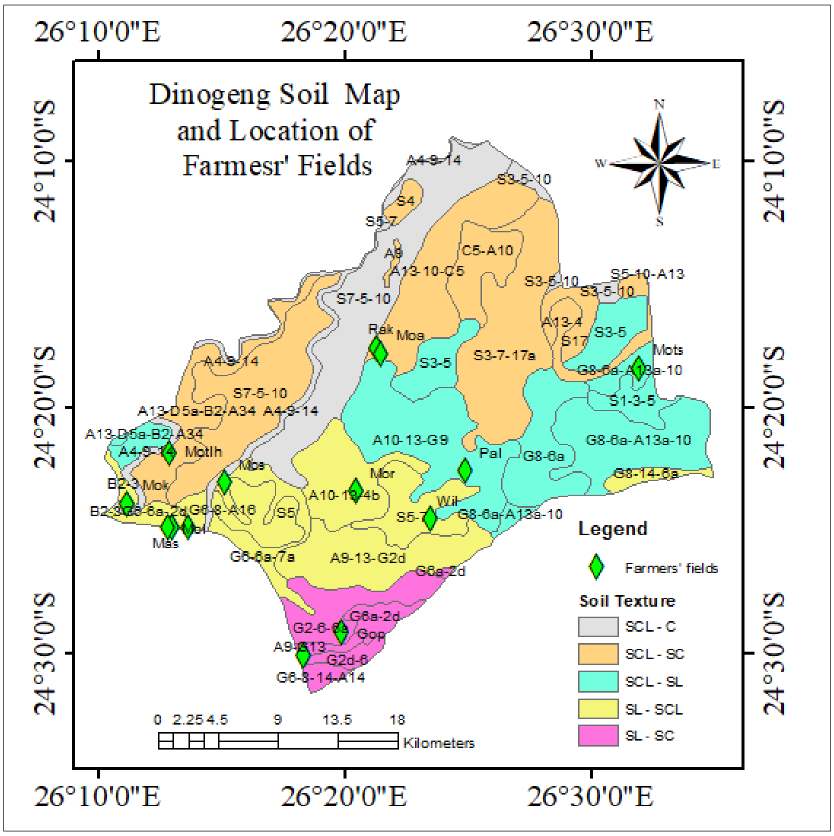

Figure 3 Dinogeng soil map with geographical locations of farmers' fields

Table 1 Soil characteristics of the study area

No	Field code	Soil unit codes	Unit description FAO (1988)	Texture	pH	OC (%)	CEC (Cmol/kg)
1	Mok	B2-3	Chromic luvisol	SL-CL	5.76	0.66	15.00
2	Mos	G6-6a-7a	Arenic Feric luvisol	LS-SL	6.96	0.33	7.00
3	Mod	G6-8-A16	Arenic Feric luvisol	LS-SL	6.96	0.33	7.00
4	Motl	A13-D5a-B2-A34	Chromic luvisol	SL-SCL	6.96	0.66	7.00
5	Moa	A13-10-C5	Chromic luvisol	SL-SCL	5.01	0.66	15.00
6	Rak	A13-10-C6	Chromic luvisol	SL-SCL	5.01	0.66	15.00
7	Mor	A10-13-4b	Chromic calcic luvisol	SL-SCL	5.01	0.66	15.00
8	Wil	S5-7	Ferallic Arenosol	SL-LS	6.96	0.20	2.00
9	Pal	A10-13-G9	Chromic calcic luvisol	SL-SCL	6.96	0.66	7.00
10	Gop	G2-6-6a	Arenic Feric luvisol	LS-SL	6.96	0.33	2.00
11	Moth	A9-G13-G2d-6	Calcic luvisol	SL-C	5.01	0.85	15.00
12	Mol	G6-6a-2d	Arenic Feric luvisol	LS-SL	6.96	0.33	2.00
13	Mas	G6-6a-2d	Arenic Feric luvisol	LS-SL	6.96	0.33	2.00
14	Mph	G6-8a-A16	Arenic Feric luvisol	LS-SL	6.96	0.33	7.00
15	Lot	A4-9-14	Calcaric Cambisol to calcic luvisol	SL-SC	6.96	0.66	15.00
16	Pos	G8-6a-A13-10	Chromic petric calcic luvisols	SCL-C	6.96	0.66	15.00
17	Phe	A13-10	Chromic calcic luvisol	SL-SCL	6.96	0.66	7.00
18	Mots	G8-6a-A13-10	Chromic petric calcic luvisols	SCL-C	6.96	0.66	15.00

Soil texture interpretation: S: sands/sandy, L: loam/loamy, C: clay, SL-LS: sandy loam to loamy sands, SCL-C: sandy clay loam to clay; Source: Soil Map of Botswana (1988)

3.2. Comparison of Soil Parameters in the period 2009-2020

The overall results in the period 2009-2020 generally show a decline in all the three soil parameters (Table 2). The pH of the baseline data ranged from 6.96 to 5.01 indicative of neutral to strongly acidic soils. In 2020, pH declined from 6.11 to 4.06 indicating slightly acidic to extremely acidic soils. The OC percentage ranged between 0.20 % (low) and 0.85% (sufficient) during 2009 and between 0.02% (very low) and 0.75% (average enough) in 2020. Cation exchange capacity (CEC) values ranged between 2.00 – 15.00 Cmol/kg during 2009, and between 0.80 – 5.62 Cmol/kg in 2020. Sandy soils generally have a very low CEC of less than 3 Cmol/kg while heavier clay soils have a much higher CEC greater than 20 Cmol/kg [13]. As Table 2 shows, the CEC conspicuously declined in the study area over an eleven-year period (2009 - 2020).

Soil pH influences the solubility of nutrients. It also affects the activity of micro-organisms responsible for breaking down organic matter and most chemical transformations in the soil. Soil pH thus affects the availability of several plant nutrients. A pH range of 6 to 7 is generally most favourable for plant growth because most plant nutrients are readily available in this range [14]. However, some plants have soil pH requirements above or below this range. According to FAO [15], optimum availability of nutrients occurs around a pH of 6.5; toxic concentrations of H and Al occur when the pH drops below 5.5; values of pH > 7.2 indicate an alkaline reaction and may be symptomatic for the immobilization of nutrients. Results from this study would imply that there is currently declining availability of nutrients and an imminent occurrence of toxic concentrations of H and Al.

Soil organic matter (SOM) content is directly influenced by soil texture and moisture content [15]. Clay rich soils have higher carbon content compared to sandy soils which are characterised by lower levels. Moist and well-aerated soils are optimal for microbial activity. Decomposition rates consequently decrease as soils become drier. However, flooded soils have lower rates of organic matter decay due to restricted aeration. High precipitation may also lead to carbon transport down the soil profile as dissolved and/or particulate organic matter. During extreme events, such as drought, SOM decomposition may initially decrease but may subsequently increase after rewetting. In this study, the overall decline in OC resulted in the decrease of SOM content during the reporting period. Table 3 shows that SOM noticeably declined over the 11-year period.

Table 2 Soil parameters in the study area before and after ISPAAD

		2009			2020		
No	**Field code**	**pH**	**OC (%)**	**CEC(Cmol/kg)**	**pH**	**OC (%)**	**CEC(Cmol/kg)**
1	Mok	5.76	0.66	15.00	4.37	0.29	3.14
2	Mos	6.96	0.33	7.00	4.93	0.19	2.20
3	Mod	6.96	0.33	7.00	4.17	0.13	1.77
4	Motl	6.96	0.66	7.00	4.78	0.35	4.31
5	Moa	5.01	0.66	15.00	5.00	0.75	3.30
6	Rak	5.01	0.66	15.00	6.11	0.39	4.41
7	Mor	5.01	0.66	15.00	4.61	0.29	2.00
8	Wil	6.96	0.20	2.00	4.90	0.20	2.15
9	Pal	6.96	0.66	7.00	5.03	0.34	1.83
10	Gop	6.96	0.33	2.00	5.00	0.75	1.80
11	Moth	5.01	0.85	15.00	5.00	0.75	1.06
12	Mol	6.96	0.33	2.00	4.06	0.23	1.35
13	Mas	6.96	0.33	2.00	4.93	0.11	3.63
14	Mph	6.96	0.33	7.00	4.40	0.10	2.07
15	Lot	6.96	0.66	15.00	5.80	0.34	5.62
16	Pos	6.96	0.66	15.00	6.00	0.75	0.80
17	Phe	6.96	0.66	7.00	5.00	0.75	4.50
18	Mots	6.96	0.66	15.00	4.28	0.02	2.56

Proper management of SOM is an important factor in conserving soil fertility in tropical areas since organic matter is the main source of nutrients for plants (Harter, 2009). Increasing organic matter can also decrease phosphorus adsorption by the soil and increase phosphorus availability to plants. However, SOM is very labile as it breaks down quickly, and is quickly lost when soil is aerated by cultivation. Loss in organic matter can be reduced by minimizing soil disturbance, but long-term productivity can only be guaranteed by appropriate management practices which include additions of organic materials to the soil such as animal manure or other organic nutrient sources.

Cation exchange capacity and base saturation are important soil measurements that help determine how a soil is managed and fertilized. High CEC indicates high nutrient storage capacity. However, in combination with low pH large amounts of exchangeable aluminium are likely to be present and this has a negative effect on plant growth [16]. Low CEC also indicates low amounts or absence of primary weatherable minerals and accumulation of secondary clay minerals such as kaolinite due to extensive weathering. High CEC is normally associated with soils having appreciable amounts of weatherable primary minerals as nutrient reserve.

The higher the CEC the more clay or organic matter present in the soil [13]. This usually means that high CEC (clay) soils have a greater water holding capacity than low CEC (sandy) soils. Low CEC soils are more likely to develop potassium and magnesium (and other cation) deficiencies, while high CEC soils are less susceptible to leaching losses of these cations. So, for sandy soils, a large one-time addition of cations e.g. potassium can lead to large leaching losses. More frequent additions of smaller amounts are better. The lower the CEC, the faster the soil pH will decrease with time.

Table 3 Estimation of SOM content in the study area before and after ISPAAD

		2009		2020		
No	**Field code**	**OC (%)**	**SOM (%)**	**OC (%)**	**SOM (%)**	**SOM Diff (%)**
1	Mok	0.66	1.135	0.29	0.499	-0.64
2	Mos	0.33	0.568	0.19	0.327	-0.24
3	Mod	0.33	0.568	0.13	0.224	-0.34
4	Motl	0.66	1.135	0.35	0.602	-0.53
5	Moa	0.66	1.135	0.75	1.290	0.15
6	Rak	0.66	1.135	0.39	0.671	-0.46
7	Mor	0.66	1.135	0.29	0.499	-0.64
8	Wil	0.20	0.344	0.20	0.344	0.00
9	Pal	0.66	1.135	0.34	0.585	-0.55
10	Gop	0.33	0.568	0.75	1.290	0.72
11	Moth	0.85	1.462	0.75	1.290	-0.17
12	Mol	0.33	0.568	0.23	0.396	-0.17
13	Mas	0.33	0.568	0.11	0.189	-0.38
14	Mph	0.33	0.568	0.1	0.172	-0.40
15	Lot	0.66	1.135	0.34	0.585	-0.55
16	Pos	0.66	1.135	0.75	1.290	0.15
17	Phe	0.66	1.135	0.75	1.290	0.15
18	Mots	0.66	1.135	0.02	0.034	-1.10

Table 4 Changes of Soil Parameters in the period 2009-2020

No	**Field code**	**pH**	**OC (%)**	**CEC(Cmol/kg)**
1	Mok	-1.39	-0.37	-11.86
2	Mos	-2.03	-0.14	-4.8
3	Mod	-2.79	-0.2	-5.23
4	Motl	-2.18	-0.31	-2.69
5	Moa	-0.01	0.09	-11.7
6	Rak	1.1	-0.27	-10.59
7	Mor	-0.4	-0.37	-13
8	Wil	-2.06	0	0.15
9	Pal	-1.93	-0.32	-5.17

10	Gop	-1.96	0.42	-0.2
11	Moth	-0.01	-0.1	-13.94
12	Mol	-2.9	-0.1	-0.65
13	Mas	-2.03	-0.22	1.63
14	Mph	-2.56	-0.23	-4.93
15	Lot	-1.16	-0.32	-9.38
16	Pos	-0.96	0.09	-14.2
17	Phe	-1.96	0.09	-2.5
18	Mots	-2.68	-0.64	-12.44
	Average	-1.55056	-0.16111	-6.75
	Std. deviation	1.076762	0.232329	5.245786669

So, sandy soils need to be limed more often than clay soils. The higher the CEC, the larger the quantity of lime that must be added to increase the soil pH; sandy soils need less lime than clay soils to increase the pH to desired levels. There is a positive correlation between CEC and SOM content. Decline in CEC negatively impacts on environmental conditions and crop yields. Thus, the ability of the soil to hold onto and supply nutrients to plants is reduced resulting in low crop and pasture yields. A decline in the resilience of the land to dry periods is very likely due to reduction in microbial activity and water holding capacity. Farmers use poor farming techniques and there is high possibility of increase in fertilizer use in the long-term. The potential to increase fertilizer use in the long-term is associated with lower levels of soil cover and more soil disturbance and increased erosion risk. Therefore, reduction in CEC has contributed to soil fertility decline and land degradation in study area.

Table 4 shows changes in pH, OC and CEC over the 11-year period. The average changes from 2009 to 2020 are -1.55 for pH, - 0.16 % for OC, and – 6.75 for CEC. The changes in pH ranged from negative 2.79 to 1.1, negative 0.64 to 0.09 for OC percentage and negative 13.94 to 1.63 for CEC. In all three soil parameters, most of the average changes are negative indicating left-tailed t-test statistic. This implies increasing adverse soil environmental conditions and marked decline of soil fertility status over the 11-year period.

4. Conclusion

The following conclusions are drawn from the study:

- The soils were becoming more acidic significantly with an average decline in pH of 1.55 ($P < 0.05$) in 2020;
- A general noteworthy decline of 0.16% ($P < 0.01$) of OC content of the soils occurred over the 11-year period (2009-2020);
- An overall significant decline of 6.75 Cmol/kg ($P < 0.01$) of CEC of soils over the 11-year period in the study area implies soil fertility decline and land degradation.

A substantial decline in all the three soil chemical properties over the 11-year period (2009-2020) could thus be attributed to soil erosion and effects of continuous crop cultivation.

Development of soil fertility strategy could be a viable option for sustainable management of the soils in the study area.

Compliance with ethical standards

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Disclosure of conflict of interest

We the authors hereby declare that there are no competing interests in this publication.

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