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# Dynamics of Soil Acidity and Some Selected Nutrients under Semi-Intensive Crop Production on Nitisols in the Ethiopian Central Highlands

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**Abstract:** Soils in the highlands of Ethiopia have multiple problems. The number and severity of the problems depend on management practices, highly local specific. This paper deals with over time dynamics of soil reaction (pH) and some selected soil nutrients viz.organic carbon (OC), total nitrogen (TN) and available phosphorus (Pav.) in Nitisols under long-term cultivation with semi-intensive production system in the Ethiopian central highlands. Measurements on the current state of soil nutrients were made from samples collected from cultivated land. For assessment of the dynamics, soil survey data of the study area worked in 1972 was used as a reference. Comparisons of the selected soil parameters were made between the time references (1972 and 2014). Farming practices were also considered to augment and understand the drivers of the soil pH and nutrients flux over time. The result revealed that almost all measured characteristics of the soil have shown dynamics at varying level over a period of about four decades. Soil acidity is markedly developed while TN and OC (measure of soil organic matter) have shown negative fluxes under cultivated Nitisols in Holeta agricultural research center in about four decades. In contrast, available phosphorus content of the soil was increased.

**Key words:** Available phosphorous · Exchangeable acidity · Soil Acidity · Soil Nutrients · Soil pH · Management Practices

## INTRODUCTION

Ethiopia is a country of diverse agro-ecologies and natural resource bases. The highlands which account for 43% of the total land area, host 88% of the human and 86% of the livestock populations [1]. Ninety five percent of the total cultivated land area also concentrates in the highlands [2]. Hence, agriculture remains the base of the national economy in the highlands of the country. Despite consistent and remarkable progress seen during the last two decades, agriculture is still subsistent and productivity is generally low [3]. Soil erosion, loss of fertility and soil acidity are some of the critical challenges facing land productivity in the highlands of Ethiopia [4-6]. Coupled with natural factors, increasing population pressure accelerates rate of land deterioration due to aforementioned factors. In the central-western highland areas soil acidity and fertility loss are extremely influencing agricultural productivity.Particularly, areas receiving high rainfall and Nitisols soil type dominated by kaolinite clay minerals are the immediate victim of theincreasing level of soil acidity [4, 7].

Nitisols which represents 12.5% of the total area is one of the dominant soil types in the highlands of Ethiopia [8]. These soils are commonly deep, well-drained red tropical soils with diffuse horizon boundaries and a subsurface horizon with more than 30% clay content [9]. They are also characterized by low bulk density and medium organic matter content. In high rainfall areas of the highlands, soil acidity development in Nitisols is associated with their good drainage conditions, low base status and release of Al upon weathering. These soils are predominantly acidic [10, 11]. Even though the effect of inherent chemical properties of parent material and climate factors are not under estimated theover use of crop residue and continuous crop harvest (without proper

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fertilization) removal of cations [12] and use of nitrogenous fertilizers [13, 14] are worsening conditions of soil acidity and continuing decline of soil fertility development in most highland areas of Ethiopia. These days, soil acidity and fertility are reaching the critical level in most central and western parts of the Ethiopian highlands.

Low understanding on soils quality responses to agricultural practices over time remains a technical gap for sustainable soil management in Ethiopia. Soils in Holeta Agricultural Research Center (HARC) are expected to be under human influence for centuries. However, cultivation of lands under research system counts only for about sixdecades. However, soil fertility related problems are becoming apparent these days.Effects from soil acidity and associated soil factors are becoming severe and limiting crop productivity. The interest in the assessment of soil fertility status has been increasing due to lack of information on trends of soil quality under cultivated land. This study is therefore designed to assess the drivers and the dynamics of soil acidity and fertility in Nitisols under semi-intensive crop production system of the central Ethiopian highlands.

## MATERIALS AND METHODS

**Description of the Study Area:** The study was conducted on research fields in Holeta Agricultural Research Center (HARC), central highlands of Ethiopia (Figure 3). HARC is geographically located between 9°3'00" – 9°5'00"N and 38°30'00" – 38°30'45" E at a distance of 30 km from Addis Ababa (Capital) along the road to Ambo. Holeta is a high-altitude area with an average 2400 m. above sea level (a.s.l). It is also a high rainfall area (1100 mm year$^{-1}$), with bimodal pattern where 70% of the total rainfall occurs in periods between June and September (main rainy season). Short rains which account for only 30% of the total annual rainfall are highly variable and occur in periods between February and April. Under rain fed, cropping during the short rains is impossible in the study area. Mean relative humidity is 60.6 while mean minimum and maximum annual temperatures are 6.2°C and 22.3°C respectively (Figure 1). The dominant soil type is EutricNitisols in association with Chromic Vertisols in some areas [15].

**Farm Characteristics and Soil Management Practices:** The study area being in the high rainfall area, inherent characteristics of Nitisols and fertility management practices pose the threat of soil acidity and associated nutrient availability to crops. The study soil used for crop research and seed multiplication which is dominated by cereals (barley, wheat, tef and recently highland maize), Pulse crops (faba bean and field pea), oil seeds (niger seed, rape seed, linseed and Irish potato from horticultural crops are widely grown. Pulse-potato/oil crops-cereals pattern crop rotationsare the most followed practice. Urea and di-ammonium phosphate (DAP) are the two major inorganic fertilizers used as sources of nitrogen and phosphorous.

**Study Approach:** The experiment had two categories considered as phase I and II. The phase I of the experiment was literature review that base on the work of Birhanu [16]. The study in 1972 which gave emphasis on Holeta Agricultural Research station categorize the area as: Unit-A: reddish brown (heavy clay); Unit-B: dark to very dark grey to greyish brown (heavy clay) and Unit-C: reddish brown (silt clay) the Unit-A category; focus of this study.

Phase II of the experiment were undertaken by collecting the soil samples; at a depth of 0-20, from all fields that are categorized as Nitisols (terraces A, D, E, F, G and H series, Figure 3). The pattern of soil sample collection was one pit in the center and four pits at radial arm within 50-80 m$^2$. By following this approach from a quarter of area a representative composite sample; 172, prepared and were taken to laboratory for analysis. Each terrace had 6-16 composite soil samples. A total of 172 composite samples were prepared for analysis.

The soil samples were air-dried, ground and sieved through a 2 mm mesh before analysis. The samples were analyzed for selected chemical properties (pH, Pav., TN, exchangeable acidity (EA) and available sulfur (Sav.). The pH of the soil was determined with the potentiometric method (1:2.5 soil: water) as described by as described by Chopra and kanwar [17]. Available phosphorus was measured using Bray II procedure [18]. Soil OC was determined as described by Walkley and Black [19] while TN was measured using the Kjeldahl method Ranist *et al.*[20].Titration method with 1N KCl leaching was used to measure exchangeable acidity[21]. Available sulfur ($SO_4^{2-}$-S) was determined following turbidity spectrometer method with 0.5M $NH_4OAc$ and 0.25M acetic acid ($CH_3COOH$) extraction [22]. Exchangeable potassium was measured with $NH_4OAc$ method [23].

**Statistical Analysis:** Data obtained from phase II of the experiment were subjected to descriptive statistics.

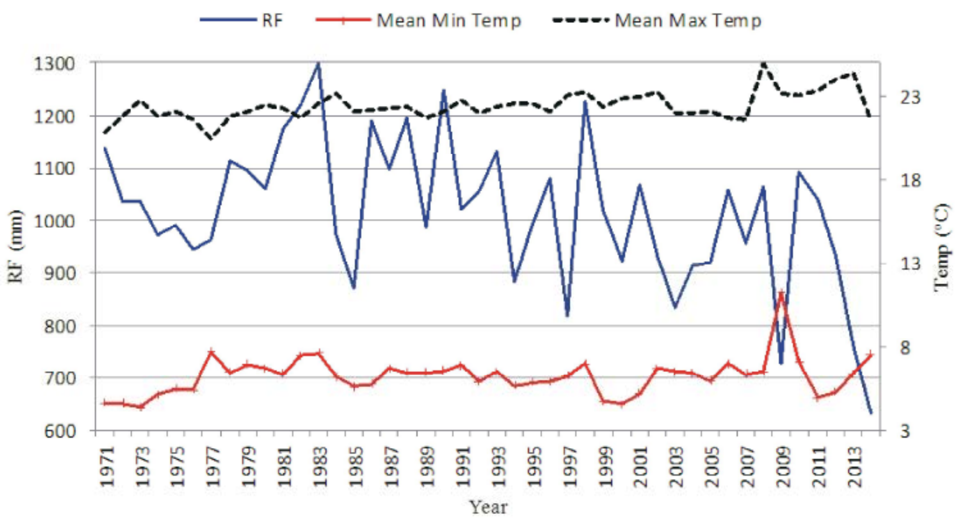


Fig. 1: Long-term weather data of the study area, Source: HARC weather station

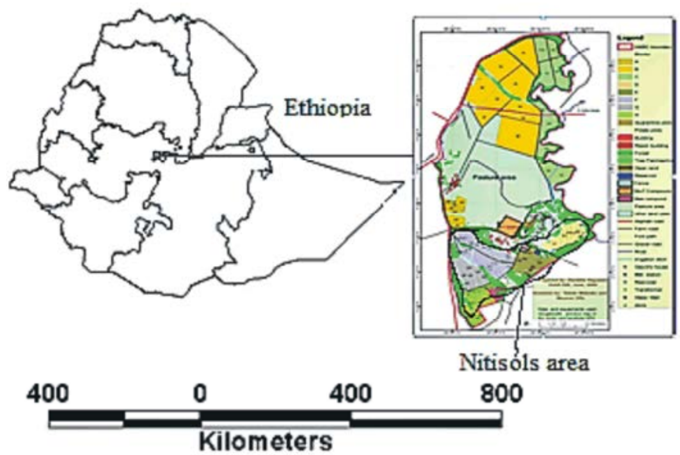


Fig. 2: Map of the Study Area (HARC)

**Nutrient Dynamics Determination**

**Determination of the Dynamics of Acidity and Some Selected Soil Nutrients (Phase I):** The dynamics of the selected soil characteristics were carried out by comparing their values at two time references (1972 and 2014). Accordingly, the review of the past study (1972) and measurements on the current status (2014) of the soil was executed.

## RESULTS AND DISCUSSION

**Brief Overview of Soil Survey Results of 1972:** The Unit-A category (focus of this study) has been intensively used for crop research and seed multiplication purposes since the establishment of the centre (1958). As indicated in Table 2, the soil under category Unit-A, which is Eutric Nitisols (BSP > 50%) was moderately acidic (mean pH= 5.7); moderate in total nitrogen (0.21%), mediumin organic carbon (2.04%), low in available phosphorus (10.2 ppm), high CEC (33.1 $cmol_{(+)}kg^{-1}soil$), high percent base saturation (65.4%) and high in potassium content (771 ppm or 1.98 $cmol_{(+)}kg^{-1}soil$) as previously mentioned [24]. Classification and interpretation of soil chemical and physical properties are based on framework indicated in Table 1.

**Current Status of Soil Acidity, Nutrient Richness and Change Scenario**

**Bulk Density:** The average bulk density (1.15 g $cm^{-3}$) of soils under Nitisols in HARC is in the range acceptable for cultivated lands dominated by clay soils. This shows good physical condition of surface mineral soils with good drainage ability [25].

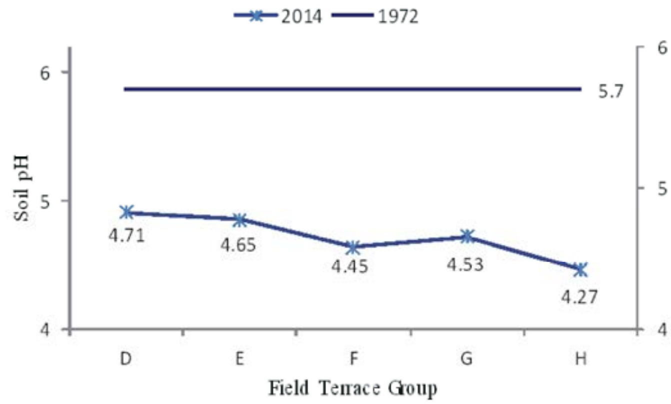


Fig. 3: Mean pH values of Nitisols under different terrace groups at 1972 and 2014, HARC

**Soil pH:** Soil analysis results revealed that, the pH of the soil category unit-A was varying between terraces with mean, minimum and maximum values of 4.52, 3.9 and 5.25 respectively. pH classification was according to [26] and the soil under terrace $H_{29}$ was ultra-acidic (pH= 3.98) while terrace $E_7$ better in pH (5.25) than others was strongly acidic (Table 2).

The overall result indicates that, except E7, all the terraces have pH values below 5.0 (very strongly acidic). Most terraces under group F, G and H are recently under extremely acidic conditions (pH < 4.5) and cover an area of about 26.7 ha (Table 2). Most terraces under group D and some under E are relatively in a better condition (pH > 4.5). Individual terraces which had a pH valuesabove 4.5 represent an estimated area of about 24.6 ha (Table2).

Despite variations between and within terrace groups were observed, the change in the average pH values of Nitisols under category Unit-A over a period of 42 years (5.7 vs 4.52, Figure 3) is generally high (from moderately acidic to very strongly acidic conditions). This is one of the remarkable changes seen in soil chemical property of Nitisolsin HARC.

Soil pH, an index that provides valuable information about nutrient availability, microbial activity, bioavailability of toxic elements and other aspects, is a very important parameter that influences several properties of the soil [5, 13, 27]. Despite target pH varies with the type of plant, most grow best at values between 5.5 and 7.0 [28]. Unlike other chemical properties of the soil, minor changes in the pH units have significant effect on nutrient availability due to the fact that for each unit decrease of pH, the $H^+$ concentration in the soil increases by a factor of 10. Generally good quality soils have pH values between 6 and 7 [29, 30].

Aluminum toxicity is also associated problem in soils with a pH below 5 as Al is soluble in water and become the dominant ion in the soil solution.Excess Al (estimated to occupy more than 60% of the effective CEC in high rainfall areas) primarily injure root apex and inhibit root elongation which leads to reduced water, nutrient uptake and net effect of reduced of growth and yield of crops [13, 31, 32].

The dramatic change seen in the pH of Nitisols in HARC experimentation fields in about four decades show absolute negligence and lack of soil quality monitoring system and corrections that resulted in serious soil chemical degradation. Natural factors (acidic parent material, high rainfall and leaching of basic cations); crop harvest [33] and continuous use of acid forming fertilizers (Urea and DAP) [13, 30] and to some extent use of crop residue as feed are proximate causes of increasing acidity of Nitisols at HARC.

**Exchangeable Acidity:** Exchangeable acidity of Nitisols (category Unit-A) in HARC is presented in Table 2. The soil analytical result revealed that, terraces labeled as D7, E4, E5, F7, F8, H28 and H29 had exchangeable acidity more than 1 cmol(+)/kg.

The presence of exchangeable aluminum and hydrogen ions are pH dependent. Exchangeable hydrogen is present in measurable quantity only at pH values below 4 while exchangeable aluminum normally occurs in significant amountsto be certainly a problem at pH values less than 5.5 [34]. In view of the pH values (< 5) in Nitisols fields of HARC, the exchangeable acidity of the soil is determinedto be dominated by aluminum which is toxic to sensitive plants (wheat and barley) if $CaCl_2$ extract level is above 0.8 ppm [35, 36].

Table 1: Soil pH and some selected soil nutrients status in Nitisols (Category Unit-A) in 1972, HARC

| | | pH | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Filed No. | Depth (cm) | $H_2O$* (1:2.5) | KCL (1:2.5) | OC (%) | TN (%) | P (ppm) | K (ppm) | CEC ($cmol_{(+)}/kg$) | BSP (%) |
| $P_1$ | 0 - 25 | 5.9 | 4.8 | 1.96 | 0.20 | 2.5 | 1314 | 24.2 | 80 |
| $P_{1**1}$ | 0 - 25 | 5.7 | 4.6 | 1.88 | 0.18 | - | 966 | 28.7 | 45 |
| $P_{46-1}$ | 0 - 20 | 6.2 | 5.0 | 2.05 | 0.20 | 2.0 | 282 | 31.5 | 67 |
| $P_{2-1}$ | 0 - 20 | 5.8 | 4.7 | 2.39 | 0.14 | 6.0 | 860 | 33.0 | 71 |
| $P_{3-1}$ | 0 - 20 | 6.0 | 4.9 | 2.12 | 0.23 | 5.5 | 938 | 29.4 | 70 |
| $P_{4-1}$ | 0 - 20 | 6.2 | 5.0 | 2.15 | 0.21 | 10.0 | 813 | 29.8 | 64 |
| $P_{5-1}$ | 0 - 20 | 5.6 | 4.5 | 1.90 | 0.21 | 10.0 | 1095 | 41.4 | 64 |
| $P_{14-1}$ | 0 - 20 | 5.7 | 4.6 | 1.63 | 0.18 | 2.5 | 1048 | 32.5 | 59 |
| $P_{15-1}$ | 0 - 20 | 6.3 | 5.1 | 1.53 | 0.21 | 3.0 | 860 | 30.1 | 78 |
| $P_{40-1}$ | 0 - 17 | 5.4 | 4.4 | 2.31 | 0.22 | 3.0 | 907 | 30.4 | 66 |
| $P_{42-1}$ | 0 - 20 | 5.4 | 4.4 | 1.78 | 0.18 | 5.0 | 250 | 28.1 | 51 |
| $P_{43-1}$ | 0 - 20 | 5.6 | 4.5 | 2.09 | 0.23 | - | 1314 | 38.0 | 57 |
| $P_{44-1}$ | 0 - 20 | 5.6 | 4.5 | 1.35 | 0.17 | 3.5 | 328 | 29.9 | 65 |
| $P_{45-1}$ | 0 - 15 | 4.8 | 3.9 | 2.81 | 0.32 | 5.0 | 172 | 30.2 | 78 |
| $P_{23-1}$ | 0 - 15 | 5.7 | 4.6 | 2.09 | 0.22 | 2.0 | 719 | 32.1 | 60 |
| $P_{24-1}$ | 0 - 20 | 5.3 | 4.3 | 2.52 | 0.24 | 2.4 | 485 | 60.1 | 72 |
| | Mean | 5.7 | 4.6 | 2.04 | 0.21 | 4.5 | 771.9 | 33.1 | 65 |

*Extrapolated from pH values done with KCl (1:2.5 suspension)
Source: Debele (1982) [24].

**Total Nitrogen:** Total nitrogen measures the total amount of nitrogen found in the soil, much of which is held in organic matter and is not readily available to plants. Soil analytical results of Nitisols (category Unit-A) in HARC indicate that, all terraces of the research fields contain moderate total nitrogen levels (< 2.0%, Table 2). The most attention-grabbing condition is very closer values of soil nitrogen in all the terraces considered in this study (std= 0.015). The change in the total nitrogen content of the soil over a period of about four decades (1972 – 2014) is remarkable. Moderate status in nitrogen content (0.21%) at 1972 has declined to low level (average TN= 0.16%, Table 3) in 2014. All the terraces investigated contain low total nitrogen levels, potential limiting nutrient for agricultural production.

Nitrogen is one of the major nutrients that higher plants require comparatively in large quantities [37]. This derives need for considerable attention that should always be paid on the occurrence and dynamics of the soil nitrogen in lands regularly used for agricultural purposes, especially cultivation land. Despite continuous use of recommended nitrogen for all crops and practices of crop rotation in HARC, soil nitrogen is depleting (Table 3). Obviously, the obtained result is essential and directive for need to design ways of acting forward to reverse the ongoing situation. Generally, large quantities of soil nutrients are removed in agricultural produces and have significant implications for maintaining the long-term nutrient balance in soils. Burning stubbles sometimes practiced in HARC causes loss of N, S and C to the atmosphere which should be avoided.

**Organic Carbon:** Organic carbon, a measure of soil organic matter, is one of the most important soil characteristics for assessing soil health. It is generally low (< 2% except terraces F15 and H29, Table 2) in all the terraces for which investigation was made. In contrast to total nitrogen, the OC contents of the terraces were varying in the ranges between 1.17% and 2.52% with a standard deviation of 0.06. Despite still in lower level, the amount of OC measured in 1972 (2.04%) was much higher than the average value obtained in 2014 (1.65%). Based on recent information (year 2014), the average organic matter content of the soil is estimated to amount 2.8%, moderate level (average structural condition and stability) [36].

Soil organic carbon is glue that holds soil in place and helps to prevent soil water and wind erosion, water and nutrient holding and maintain soil quality [38-40]. While the inorganic components of the soil nutrients are partly associated with parent materials, the organic components are all stem from decay of biomass, mainly plant materials [38]. Despite, less effort is made to quantify the required level of OC for maintaining desirable soil functions in tropics; some authors suggest 2% (about 3.44% OM) as a minimum value for maintaining stable structure and levels below 2% to result in rapid instability [41-43]. The climatic conditions of the study area (high rainfall and relatively lower temperature) and biomass production show the potential for organic carbon/organic matter accumulation in the soil. However, the declining trend in the organic carbon/organic matter content shows the lowering quality of the soil.

Table 2: Soil pH and some selected soil nutrients status (Category Unit-A) of acidic Nitisols - HARC, in 2014

| Terrace ID* | Area (ha) | pH $H_2O$(1:2.5) | EA (cmol(+)/kg) | $\rho_b$ (g/cm$^3$) | Sav. (ppm) | TN (%) | Pav. (ppm) | OC (%) |
|---|---|---|---|---|---|---|---|---|
| D1 | 2.80 | 4.78 | 0.44 | 1.15 | 6.12 | 0.15 | 11.28 | 1.66 |
| D2 | 1.68 | 4.54 | 0.39 | 1.13 | 9.20 | 0.15 | 9.63 | 1.75 |
| D3 | 0.94 | 4.59 | 0.39 | 1.10 | 6.73 | 0.15 | 7.94 | 1.54 |
| D4 | 1.90 | 4.90 | 0.42 | 1.11 | 3.12 | 0.16 | 13.66 | 1.60 |
| D5 | 0.89 | 4.80 | 0.59 | 1.15 | 5.77 | 0.15 | 13.92 | 1.57 |
| D6 | 0.41 | 4.45 | 0.53 | 1.10 | 12.50 | 0.17 | 9.14 | 1.58 |
| D7 | 0.49 | 4.93 | 1.19 | 1.05 | 14.90 | 0.18 | 12.97 | 1.88 |
| Mean | - | 4.71 | 0.56 | 1.11 | 8.33 | 0.16 | 11.22 | 1.65 |
| E1 | 2.00 | 4.64 | 0.47 | 1.11 | 5.53 | 0.14 | 12.18 | 1.40 |
| E2 | 0.89 | 4.85 | 0.39 | 1.10 | 9.61 | 0.15 | 21.32 | 1.31 |
| E3 | 0.34 | 4.40 | 0.35 | 1.10 | 12.50 | 0.15 | 12.62 | 1.60 |
| E4 | 2.36 | 4.97 | 1.13 | 1.10 | 6.84 | 0.15 | 31.97 | 1.64 |
| E5 | 1.34 | 4.38 | 1.09 | 1.14 | 5.58 | 0.15 | 20.58 | 1.65 |
| E6 | 1.34 | 4.08 | 0.75 | 1.11 | 2.50 | 0.15 | 12.54 | 1.53 |
| E7 | 1.28 | 5.25 | 0.22 | 1.12 | 3.46 | 0.15 | 22.86 | 1.49 |
| Mean | - | 4.65 | 0.63 | 1.11 | 6.57 | 0.15 | 19.15 | 1.52 |
| F1 | 0.83 | 4.75 | 0.63 | 1.14 | 2.56 | 0.16 | 16.81 | 1.94 |
| F2 | 0.70 | 4.76 | 0.18 | 1.12 | 11.86 | 0.16 | 18.59 | 1.80 |
| F3 | 1.68 | 4.9 | 0.43 | 1.14 | 8.38 | 0.16 | 18.93 | 1.68 |
| F4 | 2.36 | 4.57 | 1.00 | 1.13 | 4.91 | 0.14 | 11.7 | 1.58 |
| F5 | 1.67 | 4.22 | 0.71 | 1.13 | 9.61 | 0.15 | 7.97 | 1.55 |
| F6 | 1.41 | 4.31 | 0.72 | 1.14 | 9.78 | 0.15 | 8.00 | 1.67 |
| F7 | 0.82 | 4.10 | 1.04 | 1.35 | 10.57 | 0.15 | 8.34 | 1.68 |
| F8 | 0.81 | 4.86 | 1.10 | 1.12 | 6.41 | 0.15 | 9.63 | 1.60 |
| F9 | 0.65 | 4.89 | 0.06 | 1.08 | 2.56 | 0.14 | 6.72 | 1.33 |
| F10 | 1.00 | 4.42 | 0.36 | 1.10 | 10.58 | 0.13 | 5.15 | 1.19 |
| F11 | 1.23 | 4.44 | 0.43 | 1.11 | 9.61 | 0.14 | 6.05 | 1.19 |
| F12 | 1.60 | 4.37 | 0.15 | 1.07 | 6.41 | 0.11 | 3.93 | 1.17 |
| F13-1 | 1.68 | 4.24 | 0.45 | 1.19 | 5.91 | 0.14 | 6.80 | 1.42 |
| F13-2 | 0.74 | 4.02 | 0.82 | 1.12 | 3.21 | 0.19 | 6.31 | 1.98 |
| F14 | 0.50 | 4.22 | 0.55 | 1.15 | 3.85 | 0.16 | 6.65 | 1.78 |
| F15 | 0.85 | 4.05 | 0.90 | 1.14 | 3.21 | 0.17 | 9.72 | 2.00 |
| Mean | - | 4.45 | 0.60 | 1.14 | 6.84 | 0.15 | 9.46 | 1.60 |
| G1 | 0.44 | 5.11 | 0.06 | 1.13 | 2.89 | 0.17 | 3.20 | 1.70 |
| G2 | 0.50 | 4.98 | 0.12 | 1.06 | 1.92 | 0.16 | 4.26 | 1.57 |
| G3 | 0.91 | 4.83 | 0.08 | 1.10 | 1.92 | 0.17 | 5.97 | 1.68 |
| G4 | 2.11 | 4.45 | 0.24 | 1.09 | 3.36 | 0.16 | 7.98 | 1.76 |
| G5 | 2.39 | 4.28 | 0.30 | 1.17 | 5.19 | 0.15 | 7.03 | 1.57 |
| G6 | 1.78 | 4.23 | 0.55 | 1.16 | 4.81 | 0.15 | 7.55 | 1.54 |
| G7 | 1.40 | 4.25 | 0.81 | 1.11 | 4.65 | 0.15 | 6.72 | 1.67 |
| G8 | 0.35 | 4.08 | 0.67 | 1.13 | 5.77 | 0.15 | 5.11 | 1.57 |
| Mean | - | 4.53 | 0.35 | 1.12 | 3.81 | 0.15 | 5.98 | 1.61 |
| H22 | 0.50 | 4.78 | 0.12 | 1.16 | 9.62 | 0.17 | 17.47 | 1.59 |
| H25 | 0.79 | 4.42 | 0.19 | 1.12 | 3.53 | 0.16 | 5.26 | 1.67 |
| H26 | 0.49 | 4.26 | 0.63 | 1.13 | 3.37 | 0.17 | 5.93 | 1.91 |
| H27 | 1.51 | 4.14 | 0.77 | 1.13 | 8.81 | 0.15 | 11.21 | 1.33 |
| H28 | 0.45 | 4.01 | 1.79 | 1.12 | 10.34 | 0.17 | 6.45 | 1.93 |
| H29 | 0.51 | 3.98 | 1.65 | 1.07 | 3.37 | 0.20 | 5.04 | 2.52 |
| Mean | - | 4.27 | 0.86 | 1.12 | 6.50 | 0.17 | 8.56 | 1.82 |

*Terrace ID was given for all fields in HARC and permanently used for identification.

Table 3: Summary of some selected soil nutrients dynamics in periods between 1972 and 2014, Nitisols (HARC)

| Year | pH $H_2O$ (1:2.5) | OC (%) | TN (%) | C:N Ratio | Pav. (ppm) | Sav. (ppm) | EA (cmol(+)/kg) |
|---|---|---|---|---|---|---|---|
| 2014 | 4.52 | 1.65 | 0.16 | 10.3:1 | 9.72 | 6.41 | 0.60 |
| 1972 | 5.70 | 2.04 | 0.21 | 9.7:1 | 4.50 | - | - |
| Change | -1.18 | -0.39 | -0.05 | | +5.22 | - | - |

Table 4: Descriptive statistics of the analyzed soil parameters

| Block | D (7) | E(7) | F(16) | G(8) | H(6) | D (7) | E(7) | F(16) | G(8) | H(6) | D (7) | E(7) | F(16) | G(8) | H(6) | D (7) | E(7) | F(16) | G(8) | H(6) | D (7) | E(7) | F(16) | G(8) | H(6) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (# observations) | ----------------Mean---------------- | | | | | --------------STDV-------------- | | | | | --------------Sterr-------------- | | | | | ---------------MAX-------------- | | | | | --------------Min------------------- | | | | |
| pH ($H_2O$(1:2.5) | 4.71 | 4.65 | 4.45 | 4.5 | 4.27 | 0.19 | 0.4 | 0.31 | 0.4 | 0.3 | 0.07 | 0.2 | 0.08 | 0.1 | 0.12 | 4.93 | 5.25 | 4.9 | 5.1 | 4.78 | 4.45 | 4.08 | 4.02 | 0.2 | 3.98 |
| EA (cmol(+)/kg) | 0.56 | 0.63 | 0.6 | 0.4 | 0.86 | 0.29 | 0.4 | 0.32 | 0.3 | 0.71 | 0.11 | 0.1 | 0.08 | 0.1 | 0.29 | 1.19 | 1.13 | 1.1 | 0.8 | 1.79 | 0.39 | 0.22 | 0.06 | 0.1 | 0.12 |
| Bd (g/cm3) | 1.11 | 1.11 | 1.14 | 1.1 | 1.12 | 0.03 | 0 | 0.06 | 0 | 0.03 | 0.01 | 0 | 0.02 | 0 | 0.01 | 1.15 | 1.14 | 1.35 | 1.2 | 1.16 | 1.05 | 1.1 | 1.07 | 0 | 1.07 |
| Sav.(ppm) | 8.33 | 6.57 | 6.84 | 3.8 | 6.5 | 4.13 | 3.5 | 3.23 | 1.5 | 3.41 | 1.56 | 1.3 | 0.81 | 0.5 | 1.39 | 14.9 | 12.5 | 11.9 | 5.8 | 10.3 | 3.12 | 2.5 | 2.56 | 1.5 | 3.37 |
| TN(% ) | 0.16 | 0.15 | 0.15 | 0.2 | 0.17 | 0.01 | 0 | 0.02 | 0 | 0.02 | 0 | 0 | 0 | 0 | 0.01 | 0.18 | 0.15 | 0.19 | 0.2 | 0.2 | 0.15 | 0.14 | 0.11 | 0 | 0.15 |
| Pav.(ppm) | 11.2 | 19.2 | 9.46 | 6 | 8.56 | 2.38 | 7.3 | 4.7 | 1.7 | 4.92 | 0.9 | 2.8 | 1.17 | 0.6 | 2.01 | 13.9 | 32 | 18.9 | 8 | 17.5 | 7.94 | 12.2 | 3.93 | 1.7 | 5.04 |
| OC(%) | 1.65 | 1.52 | 1.6 | 1.6 | 1.82 | 0.12 | 0.1 | 0.28 | 0.1 | 0.41 | 0.05 | 0.1 | 0.07 | 0 | 0.17 | 1.88 | 1.65 | 2 | 1.8 | 2.52 | 1.54 | 1.31 | 1.17 | 0.1 | 1.33 |

Key: EA - Exchangeable acidity, Bd - Bulk density, Sav - available sulfur, TN - Total nitrogen, Pav - available phosphorus, OC - Organic carbon

Organic carbon and total nitrogen content of the soil affects the C: N ratio (ratio of organic carbon to total nitrogen contents) which in turn has a significant bearing on organic matter decomposition, mineralization, ammonification and nitrification in soil [44]. The C:N ratio in arable soil is usually in the range of10:1-12:1 [30]. The current state of C:N ratio of most fields under Nitisols in HARC is within this range. But the C: N ratio of soils in some fields (terraces: D6, E2, E7, F9, F11, G2, G3, H22 and H27) is lower than 10:1, indicating greater nitrification in the soil.

**Available Phosphorus:** Like nitrogen, phosphorus (P) is also an important soil nutrient that plants requirein large quantity and drives attention in management of soil fertility. Soil analytical results of the two reference years (1972 and 2014), show buildup of P in the topsoil. Recently, average available P in the soil is relatively high for characteristically low demanding crops such as wheat and barley, but low to moderate for high demanding crops such as potato widely growing in the center (Table 1, 2, 3 and 4). Specifically, soils under all fields in groups D and E terraces (except D3); and individual terraces F1, F2, F3 and F4 (positioned in mid-slope of the landscape), H22 and H27 contains significant amount of available phosphorus (Table 2). In contrast most terraces in category F, G and H have low available P. Generally soils of fields under all the terraces contain higher available P than the average amount reported in 1972, was low.

In contrast to nitrogen, P shows a significant increase in the soil. This is associated with the agricultural system (semi-intensive) in which continuous input of inorganic P has been practiced at a recommended rate for crops growing in the fields. Most agricultural soils have a large capacity to sequester P through adsorption on the soil mineral surfaces and the formation of sparingly soluble P minerals and as organic minerals [45]. The amount, forms and dynamics of soil P are influenced by soil type, environmental condition, land use and management practices [46, 47]. Despite not applied in excess of plant requirement, accumulation of plant available P in the topsoil is likely to associate with acidic soil condition (limit crop performance and P uptake; fixation of P in compounds of low solubility (aluminum phosphate) and partial return of crop residues. Generally, P is a nutrient which can be recycled and retained efficiently in the soil [48].

**Available Sulfur:** Sulfur (dissolved as sulfate) is readily leached from the soil and weathered soils in high rainfall areas frequently have a low sulfur status. Burning of vegetation results in gaseous losses of sulfur (as $SO_2$) from the farming system. Regular high levels of phosphorus application may displace sulfur from the soil matrix and contribute to sulfur depletion [49]. Sulfur distribution was highly variable among the terrace groups and within group (Table 2). All the terraces in group G contain relatively low level of sulfur while the others are mosaic. Sulfur hasn't been the focus in plant nutrition in Ethiopia. But, the recent assessment made by Ethiopian Soil Information System (EthioSIS, 2014), [50] showed deficiency of S in most areas surveyed (83%). Areas in the vicinity of HARC (farmers' field) with similar soil type were reported to be deficient. Similarly, most fields under Nitisols in HARC are also deficient. Continuous removal through plant uptake and uncommon use of S containing fertilizers are responsible for low and/or dwindling S content of the soil [51].

## CONCLUSION

Soils are living skin of earth and major support systems of human life and welfare. But, the base for sustainable use of these resources depends on maintenance of good quality. The rate of soil quality deterioration depends on intricate natural (soil type, topography, climatic conditions) and anthropogenic (agricultural practices) factors. Under natural conditions, change in soil quality is a slow process, but either accelerated or slowed by the farming practices. The results obtained from this study are not far from this fact. In about four decades, soil acidification and fertility depletion are the most conspicuous forms of soil degradation occurred in Nitisols that has been used for cultivation under semi-intensive production system. The distribution and level of acidity (strong-very strong) in the research fieldsentails the importance of the problem developed over time.

Soil acidity development, the critical issue, is generally accelerated by continuous cultivation and loss of cations through harvests (grain and straw) and use of nitrogenous fertilizers (Urea and DAP). The deleterious effects of soil acidity apparent in most fields in the center is likely related with Al and Mn toxicities, nutrients deficiency and influences on physical and biological properties of the soil. Most of all, lack of monitoring system on the dynamics of soil chemical and physical properties lasting for decades is pitfall that stems marked deterioration of soil quality in general and acidity in particular. The observed nutrient fluxes represent the impacts from cultivation and management practices perturbation to the natural nutrient cycling. To conclude, this study should be used as “quick-alarm” to begin dealing with existing problems in comprehensive and sustainable base to reverse the downgrading process of soil quality.

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