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Assessment of Soil Fertility Status with Depth in Wheat Growing Highlands of Southeast Ethiopia

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Abstract: A study to examine soil fertility status was conducted in the highlands of Southeast Ethiopia situated within latitude 07° 07' N and longitude 40° 10' E at altitude 2200 m to 2400 m above sea level. Twenty five farmers who are knowledgeable about soils of the area are purposively selected to provide insight into different soil fertility management practices. Local methods used to identify different soils and to assess the fertility status. Farmers used soil color, texture, water holding capacity, fertilizer requirement (inherent fertility) and workability as a criteria to identify different soil types. However, soil color and texture were commonly used by farmers to describe soil quality. Farmers preferred black and clay soils to white and sandy soils due to their high water holding capacity and inherent fertility. Besides, soil samples were randomly collected from the farmer's field under continuous cereal production systems. The study made up thirty-two sites and each site covered 400m^2 sampling area. Composite samples of surface and subsurface soils were collected using special auger from three depths (0-10, 10-20, 20-30cm). The laboratory analysis result indicated the soils are low in cation exchange capacity, low to medium in organic matter, slightly acidic to neutral, very high in base saturation, low to medium in exchangeable bases and moderate in both total nitrogen and available phosphorus. These soils are low to moderate in fertility that requires quite reasonable management. As a summary, the combined effect of both qualitative (local indicators of soil fertility) and quantitative (technical indicators of soil fertility) information would result in better assessment of soil fertility pattern and soil fertility management strategies to ensure food security program.

Key words: Nutrient management · Food security · Highland · Sampling · Soil survey · Soil fertility

INTRODUCTION

In permanent agricultural systems, soil fertility is maintained through applications of manure, other organic materials, inorganic fertilizers, lime and the inclusion of legumes in the cropping systems, or a combination of these. In many parts of the world the availability, use and profitability of inorganic fertilizers have been low whereas there has been intensification of land-use and expansion of crop cultivation to marginal soils. As a result, soil fertility has declined and it is perceived to be widespread, particularly in sub-Saharan Africa including Ethiopia [1-3]. Similarly, low soil fertility is recognized as an important constraint to increased food production and farm incomes in many parts of sub-Saharan Africa [4].

Soil fertility decline is considered as an important cause for low productivity of many soils [5,6]. It has not received the same amount of research attention as soil erosion; possibly as soil fertility decline is less visible and less spectacular and more difficult to assess. Assessing soil fertility status is difficult because most soil chemical properties either change very slowly or have large seasonal fluctuations; in both cases, it requires long-term research commitment.

Growing agricultural crops implies that nutrients (N, P, K, etc.) are removed from the soil through the agricultural produce (food, fiber, wood) and crop residues. Nutrient removal results in a decline soil fertility when replenishment with inorganic or organic nutrient inputs is inadequate.

About 85% of Ethiopian population are engaged in agricultural production and contribute significantly to the total export value. Previous studies of the tropical soils revealed that nitrogen and phosphorus are low and hence limiting crop production [7]. Little information is

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currently available to farmers and extension workers on soil fertility status and nutrient management. Although, Folmer *et al.* [8] employed some mathematical model based on land units and land system in order to predict potential nutrient problems, this has not presented the clear picture about the nutrient status.

The main objective of the study was to assess fertility status of the soils using indigenous local indicators of soil fertility and soil laboratory analytical data. This information and data would thus assist in developing appropriate soil fertility management strategies and options for soil fertility pattern in the area.

MATERIALS AND METHODS

Study Site: Southeast Ethiopia is known for intensive agricultural production with vast potential area, characterized by bimodal rainfall and having two distinct growing season *viz., 'Ganna'* (March-July) and *'Bona'* (August-December). The study area is situated within latitude 07° 07' N and longitude 40° 10' E at altitude 2200 m to 2400 m above sea level. The annual mean rainfall is 63.48 mm and the annual mean-maximum and minimum temperature for the experimental year is 21.23°C and 9.57°C, respectively.

Field Observation: Identification of the local indicators of soil fertility (LISF) on the study site was conducted using PRA tools, namely direct observation, informal discussion, focus group interviews and key informants. Some limited field work was also undertaken to verify some of the information and data gathered during the discussions and interviews. On the identification of the local indicators of soil fertility, the soils were broadly categorized into two groups: fertile (good) soils and infertile (bad) soils with respect to crop yields.

Household Interviews: Information on farmers' perceptions of soil fertility and the indicators they use to assess the fertility status of their fields was gathered through individual semi-structured interviews which took place in the interviewee's house. Twenty five farmers were addressed in gathering the necessary information regarding fertility assessment. Topics covered included soil fertility management practices, local methods used to assess the fertility status of a field and perceived trends in soil fertility. Information was recorded in a notebook and a check list kept making sure all topics were covered. If necessary, households were visited several times to confirm and re-check information or to speak with other members of the household. Special care was taken to ensure that the most experienced member of the household was interviewed.

Only fields owned and worked by farmers were discussed. Fields that were rented out to other farmers, or fields that were being rented by the interviewee, were excluded from the discussions to minimize errors due to a possible lack of knowledge regarding the management of these fields.

Laboratory Analysis

Soil Analysis: Soil samples were randomly collected from arable lands based on high potentials for agricultural production. Each of the 32 sites covered an area of 400 m^2 was sampled using a soil auger. Samples were collected from three soil depths *viz.,* 0-10 cm, 10-20 cm and 20-30 cm.

The technical soil fertility evaluation involved soil sampling and analysis. Soil sampling was based on the identified soil fertility groups. In each soil group, a composite soil sample of 10 sub-samples was taken from each soil depth. From the composite soil samples, parameters analyzed included pH, organic carbon, total nitrogen, available phosphorus, CEC, particle size distribution, exchangeable bases and base saturation. The pH of the composite soil samples was measured electrometrically in 1:2.5 soil water suspension [9]. Organic carbon content was determined by the wet digestion method of Walkley and Black [10] and total nitrogen by the semi-micro Kjeldahl method [11]. The available phosphorus content was determined by the Olsen's method [11]. Cation exchange capacity of the soils was determined by the neutral ammonium acetate (CH3COONH4) saturation method [12]. The particle size distribution was determined by the hydrometer method [13]. The exchangeable bases in the ammonium acetate filtrates collected above were measured by atomic absorption spectrophotometer [12].

RESULTS AND DISCUSSION

Evaluation from Farmers' Point of View: Farmers in the study area have common criteria to evaluate and identify their soils. They used soil color, texture, water holding capacity, workability and fertilizer requirement (fertility) as criteria to classify into different groups. Based on these criteria farmers of the highlands categorized their soils into: *Koticha/Guracha*, *Ambocha/dalacha, Gali* and *Daro* (Table 1).

Table 1: Soil types identified by farmers using possible indicators

	Indicators				
Soil types	Color	Water holding Capacity	Fertility status	Work ability	Limitations
Koticha	Black	High	High	Difficult	Waterlogging, hardness when dry
Galii/Arada	Variable	Low	High	Very easy	Needs more water
Ambocha/Dalacha	Grey	Medium	Low-medium	Medium	Poor soil fertility
Daro	White	Low	Medium	Easy	Poor soil fertility

In their critical analysis of how farmers in different settings classify and manage soils, Talawar and Rhoades [14] also found that farmers see soil productivity as a multi-faceted concept. It includes factors such as the soils' capacity for sustainable productivity, its permeability, water holding capacity, drainage, tillage and manure requirement and how it is easy to work. Corbeels *et al.* [15] in their study at Tigray, Ethipia, also indicated that farmers' perceptions of soil fertility are not limited to the soils' nutrient status, it also includes all soil factors affecting plant growth. Mitiku [16] also showed that the local soil classification used in Tigray only partly reflects soil nutrient status, as farmers believe that the level of nutrient is only one of several factors determining a soil's fertility.

According to Corbeels *et al.* [15], soil color is an important criterion for farmers, as it often reflects the soil's hidden parent material, which determines specific soil characteristics. The texture of the surface layer has some influence on many other soil properties and gives farmers a clear indication of to whether a soil can be cultivated after the first rains of the season.

Farmers view soil fertility in relative terms and they often relate it with the amount of rainfall in a given year. Farmers ranked '*Koticha or Guracha (*meaning black soil*)* to be the best soil in terms of productivity in the years of moderate rainfall. According to farmers in the area, due to its high water holding capacity, this soil gives better yield than other soils at times of low rainfall. The black or dark colors of soils as indicators of good soils (fertile soils) are reflections of the high amounts of organic matter content in the soils, hence high availability of plant nutrients, high capacity to retain nutrients in exchangeable forms, high moisture retention and storage and source of energy and carbon for soil micro-organisms [17-23]. The major limitation of this soil is sticky when wet and hard when dry; making it difficult to till.

On the other hand '*Gali'* is the best in seasons of high rainfall. Its main limitation is low water holding capacity; making it less productive in low rainfall years (seasons). *'Ambocha/Dalacha'* soil is the intermediate soil between '*Galii'* and '*Koticha*' in terms of water holding capacity and fertility. The main criterion to classify '*Daro*' is its white color. But, it is approximately similar to '*Galii*' in terms of fertility. '*Daro*' soils were previously homestead areas and modified by human beings by addition of manure and ashes and could be considered man made soils. Gray and Morant [24] also reported that farmers of Burkina Faso linked soil fertility with specific environmental conditions. The occurrence of light and red-colored soils is related to very low organic matter content and significant amounts of Fe and Al oxides and hydroxides in the soil. The high content of the oxides of Fe and Al is due to high content of Fe and Al in the soil parent materials. These red and light-colored soils have low soil moisture and nutrient retention capacities, acidic soil reactions and low percent base saturation, hence their local categorization as bad soils. The soils can only support plants with low nutrient and water demands, which tolerate acid soil conditions. These soils may occur in any position on the landscape but are mostly found on the top and middle positions on the landscape. Areas with red and light colored soils are mostly reserved for grazing or forestation in areas where availability of land for various agricultural or farming enterprises is not limiting.

Farmers most commonly used soil color and texture to describe soil quality. Barrera-Bassols and Zinck [25], based on their review of survey results from 25 countries in Africa, America and Asia, also reported that soil color and texture were the most commonly recognized descriptor of soil in most cultures. Farmers of the study area mentioned that black soils were fertile and had high water holding capacity, while white and red soils were most commonly used to describe poor soil. Saito *et al.* [26] also found similar description of soil color in their study of indigenous knowledge of farmers of northern Laos. With respect to soil texture, farmers preferred heavy soils (clay soils) to sand soils because of their high water holding capacity. Sandy soils are mostly highly weathered and their physical, chemical and biological attributes of soil fertility are extremely limited. The soils dry fast because physical adsorption processes they retain limited amounts of water, hence easily desorbed from the surfaces through the application of external forces. Further, most of the water in sandy soils is under the influence of the gravitational force (gravitational potential) and hence drains freely and fast through the many macro-pores present in the soil.

Soil Fertility Management Practices

Tillage Practices: Farmers used oxen to pull the local plough '*Maresha*'. Most of the farmers in the highland areas cultivate their land 4-5 times before planting cereals. They argue that increasing the frequency of tillage is the way of improving soil productivity. On the other hand, pulses are planted on marginal lands or with minimum tillage (often ploughed once). They claimed that increasing frequency of tillage for these crops could result in lodging and ultimately lower yield. Though, there are two cropping seasons, only few farmers cultivate the same piece of land for both seasons. Instead, they divided their land into '*Bona*' cropping and '*Ganna*' cropping land. The main reasons raised by farmers for not using the land for both seasons were shortage of time for land preparation after crop harvest and fear of soil fertility depletion as a result of double cropping.

Crop Residues: Farmers of the study area are well aware of the advantage of returning crop residues to soil fertility. The practice of decomposing crop residues *in situ* is locally termed '*Shemsu*' (meaning decomposition). Farmers also understood that if crop residues are not well decomposed before planting, it could compete for nutrient and 'burn' (to mean stunt the growth) the crop. But, only few farmers around 12% retain most crop residues in their field. This is because crop residues are used as construction material, fuel and source of animal feed.

Crop Rotation: Majority of the farmers' practice monocropping of cereals (wheat/barley). The easy to mechanization nature of wheat and barley have a major contribution to monocropping of cereals. Lack of crop rotation resulted in the development and build up of rusts, which is the major bottleneck for crop production. The major practice followed by farmers in this area is to rotate barley and wheat on the same piece of land. However, few farmers in some part of the highland rotated cereals with lentil, field pea, faba bean and linseed. This accounts around 74%. Instead, farmers in this region apply low rate of fertilizer as precursors are legumes.

Mineral Fertilizers: Farmers used low rate of mineral fertilizers due to the current escalating prices of chemical fertilizers. 87% farmers apply only 50 kg DAP/ha for cereals. This rate is by far lower than the blanket recommendation (100 kg DAP and 50 kg Urea) for the area. Some farmers dress the seeds with fertilizer solutions, since uniform distribution of this low rate of fertilizer is difficult with broadcasting. The use of urea fertilizer is very rare and insignificant. Farmers reported that urea fertilizer is necessary only for '*Koticha (Guracha)'* soil. This could be due to loss of nitrogen in this soil due to leaching and denitrification, as the soil is often waterlogged.

Fallowing: The study clearly depicted due to the ever increasing population pressure, long term fallowing is currently abandoned in the study area. But, farmers know the benefit of fallowing to restore soil fertility. Currently, the common practice in the area is seasonal fallowing i.e. leaving the land fallow for one or two seasons. This is however, short period for restoration of soil fertility. Allan [27] believes that the fallow period should not be less than eight years on the best soils. Mansfield [28] on the other hand, claims that the required fallow period for the soil recovery is about 15-20 years.

Laboratory Analysis: Particle size distribution and analysis of soil texture indicates that the lower depth soils were highly dominated by clayey soils which unlike for surface soil (0-10cm) represented by silty-clay. Corresponding to all soil depths, the median of sand, silt and clay fractions was 10.3%, 20.2% and 69.5%, respectively. The clay content ranged from 47% in the upper surface to 87.7% with successive increase along soil depth. The silt/clay ratio of topsoil was relatively high. As reported by Ribeiro [29], the ratio greater than 0.12 has been considered as less weathered soils. Besides, the lower clay content in the topsoil suggests clay eluviation [30].

Soil Reaction: The pH in water varied considerably among sample sites. The range was reported from 6.3 to 7.1 (neutral soil reaction) and median 6.7. Soil pH in the given range regarded as slightly acidic to neutral [31] which could be taken safest for crop production. However, it is likely to cause acid potent cations in the long run as favored by the high rainfall prevailing in the area which encourages leaching of base forming cations from the surface and their accumulation down soil depth.

Table 2: Means of soil properties of agriculturally important highland soils of Southeast Ethiopia

	Chemical properties									Particle size				
	pH	OC (%)	Ca	Mg	K	Na	Exch. Acidity	CEC		N %	BS %	Sand %	Silt %	Clay %
Soil depth (cm)			$cmol_c\ kg^{-1}$						P_{av} (mg kg^{-1})	%		%		
0-10	6.8	1.70	2.41	0.66	0.41	0.14	0.05	3.67	7.3	0.12	98.6	16.0	37.0	47.0
10-20	7.1	0.91	3.50	0.65	0.30	0.19	0.02	4.66	6.6	0.10	99.6	7.1	19.0	73.9
20-30	6.3	0.76	3.45	0.73	0.43	0.21	0.03	4.85	6.5	0.10	99.4	7.8	4.5	87.7

Approximately 88% of the samples were within adequate levels of pH (6.3-6.9) and 12% of the samples have pH greater than 6.5 and as high as 7.3. In the subsurface layer (20-30cm), 24% of the soil samples had a pH less than the top soil.

Soil Organic Matter: The soil organic matter ranged from 1.34% to 2.92% indicates low to medium. The median was 1.93%. These values are rated as medium [31]. Equivalent to 36.4% of the samples had low to very low level for the subsurface samples whereas 86% of the samples taken from the surface were within the medium range (2.0%-4.0%) [31]. As expected, the amount of total carbon decreased with increasing depth.

Cation Exchange Capacity: Cat ion exchange capacity is the dominant factor in measuring soil fertility which affects exchange of ions on the clay surface. The low CEC value in the area affects cereal production since wheat yield per unit area declining in time due to fertility degradation. The median of CEC was 4.39 $cmol_c\ kg^{-1}$ ranged from 3.67 to 4.85 $cmol_c\ kg^{-1}$ rated as low to medium [31]. Similarly, CEC value analyzed from the given finding had less than 7.5 $cmol_c\ kg^{-1}$ [31], the minimum level for adequate exchange capacity according to INIA [31], soil fertility capability classification system. But, samples analyzed for soil depths 10-20 and 20-30cm by far greater and significant than surface soil sample (0-10 cm) though they were statistically at par which probably due to considerable concentration of base forming cations shifted to the lower part of the soil. The low to medium CEC of the soils could be attributed to the low organic matter content as well as the low to medium levels of clay content in the upper soil surface.

Exchangeable Bases and Available P: Interpretation of soil exchangeable bases showed the median of extractable Ca was 3.12 $cmol_c\ kg^{-1}$ ranged from 2.41 to 3.5 $cmol_c\ kg^{-1}$ for the entire rooting depth. The concentrations of Ca in all soil depths were rated as low [31]. Similarly, extractable Mg ranged from 0.66 to 0.73 $cmol_c\ kg^{-1}$. The median was 0.68 $cmol_c\ kg^{-1}$. Samples collected from all depths indicated almost all measurements of Mg fall in the medium level. With regard to K, the minimum level was 0.3 $cmol_c\ kg^{-1}$ and the maximum was 0.43 $cmol_c\ kg^{-1}$. Such a range fall in the lowest level for K which definitely indicate its response to chemical fertilizer applications. Regarding Na concentration, it could be detected with successive increase with increasing soil depth. As depicted in Table 2, it falls in the range 0.14 to 0.21 $cmol_c\ kg^{-1}$ which was exist in the lowest possible level [31]. This could be taken as an opportunity because Na concentration is not recommendable to high level as it deteriorates soil structure and make the soil liable for soil erosion and devoid of beneficial organisms.

The available P (Olsen P) at 0.5 mg kg^{-1} put as a threshold for the lowest level and this found to be moderately available since the analyzed value in all soil depths fall in the range 5.0-10.0 mg kg^{-1} [31]. On the other hand, soil pH was significantly low in the lower layer as compared to top soil exhibited its effect on phosphorus availability in a similar fashion in the lower layer probably because of P sorption capacity of the soil in the subsoil layer. Most limiting nutrient in tropical soils can be regarded as soil nitrogen followed by phosphorus [7]. The finding of the study on the basis of soil analysis at various soil depths revealed total nitrogen was suggested in moderate level though values were statistically at par. This is a nutrient which determines crop yield under field conditions as cereals by nature incapable of fixing the free atmospheric nitrogen appreciably like legumes. Such findings indicate nitrogen level is just at the junction of the lowest level signifying its potential to limit field crop yield in the area. Such risk might be associated with improper management of the resource under subsistence farming and inherent volatility nature of the element in tropical soils. As an important soil property base saturation of the study sites ranged from 98.6 to 99.6% was categorized as very high level (Table 2).

In conclusion, based on the soil test data, the soil fertility attributes in the highlands of Southeast Ethiopia is becoming limiting for crop production, include low to medium organic matter content, moderate in both total nitrogen and available phosphorus and low CEC. Any soil management strategy for sustained wheat production should address the above attributes accordingly. The local indicator soil fertility (LISF) and technical indicators of soils fertility (TISF) are in conformity with assessing the fertility status of the soils. The LISF being qualitative are prone to wrong interpretation by inexperienced farmers, extension staff and researchers. But, the combined effect of both qualitative and quantitative information would result in assessment of soil fertility pattern and soil fertility management strategies. The base line information showed LISF gave a broad sense of fertility evaluation of the soils for crop production. More importantly, combination of the LISF and soil analytical data produced suitable land classes. The major soil fertility constraints in the study area include low to medium organic matter content, moderate in both total nitrogen and available phosphorus and low CEC.

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