



## Assessment of Soil Fertility Status at Dawja Watershed in Enebse Sar Midir District, Northwestern Ethiopia

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### Authors' contributions

This work was carried out in collaboration between both authors. Author MA designed the study, wrote the protocol, wrote the first draft of the manuscript, managed the literature searches and analyses of the study performed. Author KK managed the experimental process and data analysis. Both authors read and approved the final manuscript.

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### ABSTRACT

Information on soil fertility status is key in predicting the relative response of soils to fertilizer application and adopting appropriate management practices. The present study was conducted to assess the fertility status of the soils of the Dawja Watershed in Enebse Sar Midir District. 21 composite soil samples were collected from the 0-20 cm soil depth of 7 land units, identified based on their slope and management practices. Except available phosphorus, all the soil parameters were significantly ( $P < 0.05$ ) affected by differences in land units. The textural class of the soils varied between sandy clay loam and sandy clay. The bulk density of the soils under the different land units ranged between 1.32 and 1.41 g cm<sup>-3</sup> and the total porosity varied from 46.66 to 50.10%. The pH of the soils ranged from 5.7 to 6.8. The organic matter content of the soils was generally low and ranged between 1.17% in cultivated land unit to 2.46% in grazing land unit soils. The total nitrogen content of the soils ranged from 0.13 to 0.19%. Available P (Olsen) was generally high in all the land units and ranged between 17.92 to 23.02 mg kg<sup>-1</sup>. The results further showed that the

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soils were generally rich in exchangeable basic cations with CEC ranged between 18.13 cmol(+) kg<sup>-1</sup> in soils of strongly sloping cultivated land unit to 41.87 cmol(+) kg<sup>-1</sup> in soils of gently sloping land unit. The percent base saturation of the soils varied between 62.30 and 92.20%. The extractable micronutrients (Fe, Mn, Zn and Cu) of the soils were above their respective critical levels, which indicate that they are not limiting crop production at the moment. In general, soils of the study area are good in their selected physical and chemical properties for plant growth except organic matter and total nitrogen. Therefore, the soil fertility management should focus on scenarios that could improve the organic matter and nitrogen levels for improving crop production on a sustainable basis.

*Keywords: Critical level; land unit; soil fertility; sufficient; sustainable.*

## 1. INTRODUCTION

Depletion of soil fertility is paramount problem in reducing productivity of soils and food insecurity in SSA including Ethiopia [1]. Ethiopia is trapped in a vicious cycle of poverty and about 85-90% of its population depending on agriculture [2]. The same source indicates that the country needs to increase food production in grain equivalent, by at least one million metric tons to meet a rapidly growing population demand. However, Ethiopia faces a wider set of chemical and physical soil fertility issues that interact and include loss of soil organic matter, macronutrient and micronutrient depletion, topsoil erosion, acidity, salinity and deterioration of other physical soil properties. These problems relate with forest clearance and soil exposure, poor crop cultivation practices and overgrazing. In addition indirect causes such as poverty, insecure land tenure and population growth have led to soil fertility degradation [3].

The Northwest Ethiopian highlands are most severely affected by nutrient depletion due to intensive cultivation without nutrient replenishment spanning over decades [4]. As the same source indicated leaching of nutrients by excess of rainfall and irrigation water, soil erosion and high crop nutrient mining together with low replenishment rate, have also great role. Over 95% of the population of the Enebse Sar Midir District is engaged in agriculture but earns low income due to high coverage of marginal fertile soils, which may be attributed by depletion of soil nutrients through crop removal, erosion and low and inadequate use of fertilizers [5].

On most cultivated lands of Dawja Watershed, continuous cultivation for decades without applying nutrients (but now in few exceptional areas Urea and DAP are used) and removal of crop residues are common. Apparently, this could have negatively affected soil fertility and productivity in the area. In addition, the area receives high rainfall, which causes leaching and

removal of plant nutrients, and thus, reduce the crop productivity of most cultivated lands [5].

Understanding of the soil fertility status from empirical and scientific studies is vital to design proper soil management strategies to improve soil fertility and productivity for sustainable development. In general, investigating the fertility status of the soils under the existing uses is valuable to provide information on nutrient status of the soil, predict the relative response of soils to fertilizer application and design appropriate management strategies. Therefore, the objective of the study was to assess the fertility status of the soils of the Dawja Watershed in the Enebse Sar Midir District.

## 2. MATERIALS AND METHODS

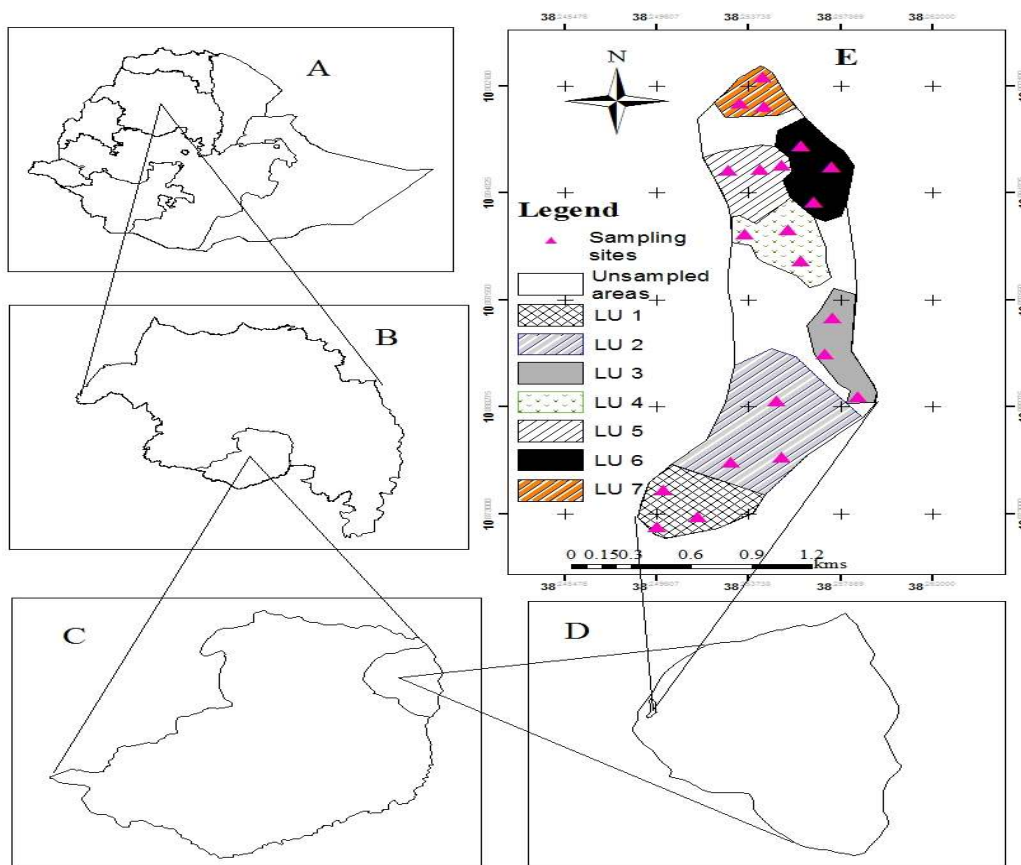
### 2.1 Study Area

The study area, Dawja Watershed, is found in Enebse Sar Midir District, East Gojjam Zone, Amhara National Regional State at about 360 km northwest of Addis Ababa. The elevation ranges from 2629 to 2965 meter above sea level and dominated by 0-30% slope. The Watershed lies within 10° 52'-10° 54' N and 38° 14'-38° 15' E (Fig. 1). According to the Regional Meteorological Office recorded data for four years (2008-2011), from Bahir Dar Meteorology station, the study area receives average annual rainfall of 1053 mm and mean minimum and maximum temperature of 10 and 23.4°C, respectively. The mean monthly distribution of rainfall and temperature of the area are indicated on Fig. 2.

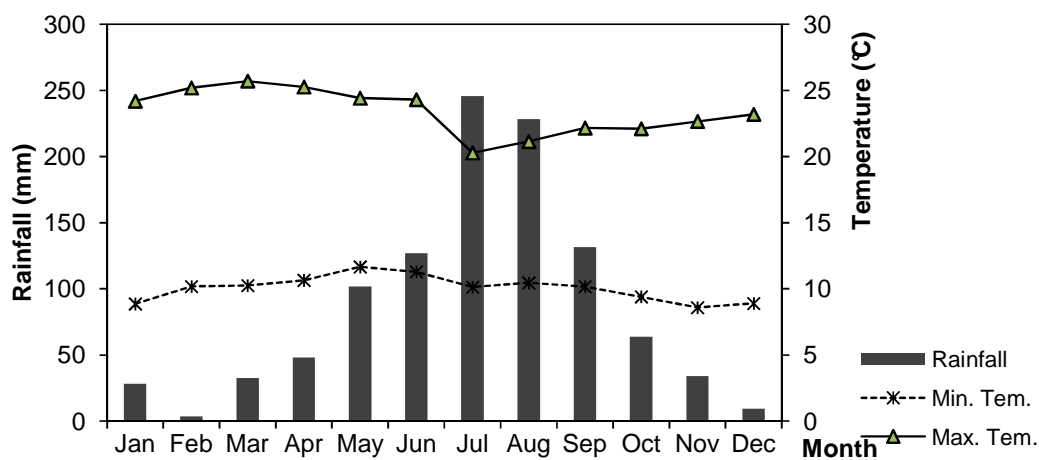
Vertisols are the dominant soil types in Dawja Watershed [6]. The Watershed covers a total land area of 233 ha. Of this, 140.5 ha (60%) is put under cultivation, 25 ha (11%) is for grazing, 29.5 ha (13%) is for settlement and 38 ha (16%) is covered by plantation. Wheat (*Triticum spp*), tef (*Eragrostis tef*), barley (*Hordeum spp*), faba bean (*Vicia faba*), chickpea (*Cicer arietinum*) and

grass pea (*Lathyrus sativus*) are the principal crops grown in Dawja Watershed. Cattle, sheep,

goat and equine constitute major livestock in the study area [5].



**Fig. 1. Location map of the study area: (A) Amhara Region in Ethiopia, (B) East Gojjam Zone in Amhara Region, (C) Enebse Sar Midir District in East Gojjam Zone, (D) Dawja Watershed in Enebse Sar Midir District and (E) Dawja Watershed**



**Fig. 2. Mean monthly distribution of rainfall and minimum and maximum temperature for four years (2008-2011) of the watershed**

## 2.2 Soil Sampling

In 2013/2014 a preliminary field observation was carried out using the topographic map (scale 1:50,000) of the study area and through transect walk. During the observation, parameters that were expected to lead for variability of soil fertility, mainly slope gradient and soil management practices, were recorded to classify the study area in to different land units. Slope gradient and elevation of the study area were measured by using clinometers and global positioning system (GPS), respectively.

The study area was first demarcated based on slope gradient. Then after, management practices, basically, cropping patterns of the study area were taken in to account, to determine the final land units. Generally, based on the field observation, similar sites (in terms of slope gradient and management practices) were demarcated on the ground that represents the respective land unit. Accordingly, seven land units were demarcated and from each land unit, samples were collected in three replications (Table 1).

Disturbed soil samples were collected by using auger at 20 cm soil depth following the standard procedures. A total of 21 composite samples were collected from the seven land units. The samples were air-dried, crushed and passed through 2 mm sieve for all soil parameters except for organic carbon and total nitrogen, which passed through 0.5 mm sieve. Similarly, 21 undisturbed samples were collected by using core samplers that were 5 cm diameter × 5 cm length, for the analysis of soil bulk density. Then, the samples were labelled and taken to the Haramaya University Soil Chemistry Laboratory for the analysis of physicochemical properties using the standard procedures.

## 2.3 Soil Analysis

Soil texture was analysed by determining the percentage of sand, silt and clay in each soil sample by following Bouyoucos hydrometer method [7]. Once the particle size distribution was determined in percent, the textural class of the soil was assigned using USDA textural triangle classification system [8]. Bulk density of the samples was estimated from undisturbed soil samples using the core method as described in Sahlemedhin and Taye [9]. Total porosity of the soil was derived from the bulk and the particle densities as:

$$f(\%) = (1 - pb/pd) \times 100$$

where  $f$  = total porosity,  $pb$  = soil bulk density and  $pd$  = soil particle density which was assumed to have the generally used average value of  $2.65 \text{ g cm}^{-3}$ .

The pH ( $\text{H}_2\text{O}$ ) of the soil was measured potentiometrically in the supernatant suspension of 1:2.5 in soil: water ratio using digital pH meter following the procedure outlined by Sahlemedhin and Taye [9]. The soil organic carbon was determined by the wet oxidation method [10] in which the sample was first digested with potassium dichromate in sulfuric acid solution and titrated with 0.5 N ferrous sulfate solution, and percent organic matter was computed by multiplying the percent soil organic carbon by a conversion factor of 1.724. Total N content of the soil was determined by wet-digestion, distillation and titration procedures of the Kjeldahl method as described by Black [11]. Then after, C: N ratio was computed by dividing organic carbon to total nitrogen. The available phosphorus content of the soil was determined using Olsen extraction method [12].

**Table 1. Description of the land units identified in the watershed (2013)**

LU	Slope gradient categories		Management practices		
	Slope (%)	Class and description	Previous crop	Current crop	Type of fertilizers used
1	10.4-12.5	07-strongly sloping	Chickpea	Wheat	urea and DAP
2	2.5-4.5	05-gently sloping	<i>Teff</i>	barely (grass pea)	None
3	10-15	07-strongly sloping	Wheat	Wheat	urea and DAP
4	15-20	08-moderately steep	grazing land	grazing land	--
5	8-9.5	06-Sloping	Wheat	<i>Teff</i>	urea and DAP
6	7-10	06-Sloping	Barely (grass pea)	<i>Teff</i>	urea and DAP
7	5-6.5	06-Sloping	pea and bean	Wheat	urea and DAP

\*LU= Land Unit, \*the crop written in parentheses is grown as a double crop for respective land unit, \*classes represented by 05, 06, 07 and 08 have a slope gradient of 2-5, 5-10, 10-15 and 15-30%, respectively (FAO, 2006b)

The exchangeable bases were determined through extraction method with 1 M ammonium acetate at pH 7. Amounts of Ca and Mg ions in the leachate were analyzed by atomic absorption spectrophotometer, while K and Na ions were analyzed by flame photometer. Cation exchange capacity was determined by leaching the soil sample with 1 N ammonium acetate solution followed by leaching with neutral salt to displace the adsorbed ammonium ( $\text{NH}_4^+$ ). Thereafter, estimated titrimetrically by distillation of ammonium that was displaced by sodium. The percent base saturation of the soil was calculated as the percentage of the sum of the basic exchangeable cations (Ca, Mg, K and Na) to the CEC of the soil [13]. Micronutrients (iron, manganese, zinc and copper) were extracted with DTPA as described by Lindsay and Norvell [14], and then determined by atomic absorption spectrophotometer in comparison with standards at 248.3 nm, 279.5 nm, 213.9 nm and 324.7 nm wavelength for Fe, Mn, Zn and Cu, respectively.

The analysis of variance (ANOVA) was performed to assess the significant level of difference in soil parameters among land units using the general linear model (GLM) procedure of the statistical analysis system (SAS) software version 9.00. Significantly different means ( $P < 0.05$ ) were separated by using the Duncan's multiple range test (DMRT). Critical levels of soil parameters were used to consider the fertility status and to make agronomic interpretations for the soil test results of the study area.

### 3. RESULTS AND DISCUSSION

#### 3.1 Soil Texture

There were statistically significant differences ( $P < 0.01$ ) in particle size distribution among the land units (Table 2). Accordingly, the lowest sand content (46%) was recorded on land unit 2, while the highest sand content (57.67%) was observed on land unit 1. Similarly, the lowest silt fraction (14%) was recorded in land unit 2, while the highest silt content (26.34%) was in land unit 3. On the other hand, the lowest clay content (23.33%) was recorded in land unit 3, whereas the highest clay content (40%) was recorded in land unit 2.

Although land use system has its own effect, the variations of particle size distribution among the land units might be due to the slope gradient difference, since removal of the finer particles (mainly clay particles) by erosion is enhanced on

the upper slope areas while deposition of these particles occur on the lower slope areas. On the other hand, frequent cultivation might have enhanced weathering of primary particles and contributed for the high clay fraction in the relatively low sloping areas. Nevertheless, this practice increased the sand fraction in the relatively sloppy areas by exposing finer particles to erosion process. Similarly, [15] reported that soil management practices have indirect role in the processes of erosion and deposition, and illuviation and weathering which can change the texture of soils. In contrary, soil texture cannot be easily changed by management practices due to its intrinsic property [16,17].

According to USDA system of soil texture classification [8], most soils of the Watershed are categorized under sandy clay loam (Table 2). In these soils, most field crops could grow well as these soils have a potentially well-balanced capacity to retain water, form a stable structure and provide adequate aeration.

#### 3.2 Bulk Density and Total Porosity

Variation in soil bulk density due to differences in land units was significant ( $P < 0.01$ ). The lowest and highest bulk densities values were recorded for soils from land unit 2 ( $1.32 \text{ g cm}^{-3}$ ) and both land unit 3 and 1 ( $1.41 \text{ g cm}^{-3}$ ) of the Watershed, respectively. The variation of soil bulk density among the land units might be attributed to the variation of soil texture and disturbance of soil particles with erosion and animal contact. For instance, the relatively lowest value of bulk density in land unit 2 ( $1.32 \text{ g cm}^{-3}$ ) could be due to the high clay fraction, porosity and less disturbance of the soil by erosion process, as this land unit has relatively level (gently sloping) land position. But, the reverse is true for land unit 3 and 1 (Table 2).

The bulk density of the studied soils at the depth of upper 20 cm were found to be less than  $1.61 \text{ g cm}^{-3}$ , which is common and acceptable for sandy clay and sandy clay loam soils [18]. Therefore, the bulk density is ideal for root activity, water infiltration into soil, and overall growth of crops, and indicates that the soils of the study area are not compacted.

Similar to the bulk density, significant variation in total porosity were observed ( $P < 0.01$ ) among the land units. The lowest total porosity (46.66%) was recorded on land unit 3, while the highest total porosity (50.10%) was on land unit 2. The

lowest total porosity recorded in land unit 3 could be attributed to the high bulk density, low clay content and low organic matter content (Table 2 and Table 3). On the other hand, the highest total porosity was recorded in the land unit with the highest clay content, implying the positive effect of clay content on total porosity.

According to [19] rating of total porosity, the percent total porosity values of all the land units were very high (greater than 40%). This indicates that the study area soils are physically fertile with regard to total porosity.

### 3.3 Soil Reaction

Soil pH (H<sub>2</sub>O) was significantly ( $P < 0.01$ ) varied across the land units. The lowest pH value (5.7) was recorded on land unit 1, whereas the highest pH (6.8) was obtained on land unit 2 (Table 3). According to [20] rating of soil pH, the soils in the Watershed represented by land units 1, 3 and 4 were moderately acidic, while land units 5, 6 and 7 were slightly acidic and land unit 2 was neutral.

The moderately acidic level of pH in soils of land units 1, 3 and 4 could be probably due to loss of basic cations through runoff since those land units have relatively steeper slopes (Table 1). This in turn increases the activity of H<sup>+</sup> ion in the soil solution, reduces soil pH and increases soil acidity. On the other hand, the presence of relatively high Fe and Mn nutrients (Table 5) under these land units might have contributed for lower values of pH as compared to the other land units that have slightly acidic and neutral pH ranges.

Moreover, the variation of pH across the land units of cultivated land is attributed to the differences in management practices such as crop rotation and fertilization rate (Table 1). In line with this finding, [21] reported that depletion of cations and continuous use of ammonium-based fertilizer (DAP and urea) are main causes for soil acidity in cereal based cultivated fields. The soil pH values of all land units of the study area were between 5.7 and 6.8, which is suitable for crop production as most nutrients for field crops are available at pH values of more than 5.5 and less than 7.0 [22].

### 3.4 Organic Matter, Total Nitrogen and C to N Ratio

The ANOVA revealed that organic matter values varied significantly ( $P < 0.01$ ) among the land units. The lowest OM was recorded in soils of the strongly sloping land units 1 and 3, and sloping land units of 5 and 6, whereas the highest level of OM was recorded in soils of the moderately steep slope grazing land unit 4 (Table 3).

The variation could be contributed by the difference in land use type (grazing versus cultivated) and slope gradient. For instance, the relatively highest values of OM content was recorded at the grazing land unit (land unit 4) than the other cultivated land units. This could be due to the reason that continuous tillage practices loosen the soil system and enhanced the process of OM decomposition in the cultivated lands than the grazing land. Similarly, [23] reported that the depletion of organic carbon was higher in cultivated land than grazing land in soils of Guto Gida District, Western Oromia.

**Table 2. Selected soil physical properties of the Dawja Watershed soils under different land units**

LU	Particle size (%)			Textural class	<i>pb</i> (g cm <sup>-3</sup> )	f (%)
	Sand	Clay	Silt			
1	57.67 <sup>a</sup>	24.00 <sup>e</sup>	18.33 <sup>c</sup>	Sandy clay loam	1.41 <sup>a</sup>	46.81 <sup>d</sup>
2	46.00 <sup>d</sup>	40.00 <sup>a</sup>	14.00 <sup>e</sup>	Sandy clay	1.32 <sup>d</sup>	50.10 <sup>a</sup>
3	50.33 <sup>b</sup>	23.33 <sup>e</sup>	26.34 <sup>a</sup>	Sandy clay loam	1.41 <sup>a</sup>	46.66 <sup>d</sup>
4	47.00 <sup>d</sup>	34.67 <sup>b</sup>	18.33 <sup>c</sup>	Sandy clay loam	1.34 <sup>cd</sup>	49.26 <sup>b</sup>
5	50.67 <sup>b</sup>	33.33 <sup>bc</sup>	16.00 <sup>d</sup>	Sandy clay loam	1.35 <sup>c</sup>	49.13 <sup>b</sup>
6	48.67 <sup>c</sup>	31.67 <sup>c</sup>	19.66 <sup>b</sup>	Sandy clay loam	1.36 <sup>bc</sup>	48.67 <sup>bc</sup>
7	51.67 <sup>b</sup>	29.00 <sup>d</sup>	19.33 <sup>bc</sup>	Sandy clay loam	1.38 <sup>b</sup>	48.06 <sup>c</sup>
LSD (0.05)	1.39	1.93	1.15	-	0.02	0.75
SE (±)	0.45	0.63	0.37	-	0.01	0.24
CV (%)	1.55	3.51	3.44	-	0.82	0.88

Note: - Values in the same column followed by the same letters are not significantly different at 0.05 level of significance; *pb* = bulk density; f = total porosity; LSD = least significant difference, SE = standard error,

CV = coefficient of variation

**Table 3. Soil pH, organic matter, total nitrogen, carbon to nitrogen ratio and available phosphorus levels of Dawja Watershed soils under different land units**

LU	Soil parameters				
	pH (H <sub>2</sub> O)	OM (%)	TN (%)	C: N	Av.P (mg kg <sup>-1</sup> )
1	5.7 <sup>c</sup>	1.17 <sup>c</sup>	0.14 <sup>bc</sup>	4.68 <sup>cd</sup>	17.92
2	6.8 <sup>a</sup>	1.67 <sup>b</sup>	0.18 <sup>ab</sup>	5.47 <sup>bc</sup>	22.50
3	5.8 <sup>c</sup>	1.31 <sup>c</sup>	0.18 <sup>a</sup>	4.17 <sup>d</sup>	23.02
4	5.9 <sup>c</sup>	2.46 <sup>a</sup>	0.19 <sup>a</sup>	7.50 <sup>a</sup>	20.94
5	6.5 <sup>ab</sup>	1.38 <sup>c</sup>	0.13 <sup>c</sup>	6.37 <sup>b</sup>	22.91
6	6.6 <sup>ab</sup>	1.30 <sup>c</sup>	0.13 <sup>c</sup>	6.01 <sup>b</sup>	20.54
7	6.1 <sup>bc</sup>	1.86 <sup>b</sup>	0.17 <sup>ab</sup>	6.36 <sup>b</sup>	22.33
LSD (0.05)	0.52	0.29	0.03	1.09	NS
SE (±)	0.17	0.09	0.01	0.355	1.69
CV (%)	4.72	10.19	11.65	10.22	13.67
Critical level	5.5-7.0	3.4	-	8-12	8

On the other hand, regarding with cultivated land units only, relatively higher content of OM was observed in soils of land unit 7 (1.86%) and 2 (1.67%). This might be due to their relatively level slope gradient (Table 1) where the soil moisture storage is better, resulting in better biomass production. Furthermore, the expected impeded drainage could also slow down the decomposition process. This result is in agreement with the work of [21] in Nitisol of Southwestern Ethiopia.

According to the rating system established by [20], organic matter content of all the land units were categorized under low and below the critical level (3.4%). The remarkable low level of soil OM in the study area could be due to limited use of organic amendment for the maintenance and/or improvement of soil organic matter. Low replenishment of organic sources together with continuous cultivation disperses aggregates and exposes the OM in them to further decomposition. In agreement with this finding, different reports indicate that most cultivated soils of Ethiopia are poor in organic matter content [24,25,4,26].

The relatively lowest and highest values of total nitrogen were recorded for both land units 5 and 6 (0.13%), and for land unit 4 (0.19%), respectively (Table 3). Total nitrogen of all the land units in the present study was in the range of medium based on the rating suggested by [20], and its content was less than 0.25%. The notable deficiency of total N in the study area might have resulted from low level of soil organic matter content and mineralization of the existing soil OM following cultivation and communal free grazing. The limited use of nitrogen containing inputs like commercial fertilizer and plant and

animal residues in such continuous cropping land and communal grazing land has contributed to the loss of total N throughout the Watershed.

In the study area, crop residues are collected for animal feed, fuel, thatching and temporary construction purposes. Similarly, animal dung and wastes are collected for fuel and temporary construction. These could be probably the major factors contributing to reduce soil OM, and thereby to the decline of total nitrogen in the soil system. In addition to this, as the study area receives high amount of rainfall, leaching could be the other additional factor for nitrogen deficiency.

Generally, nitrogen is found to be one of the limiting plant nutrients in the study area and increasing productivity without application of N source fertilizers will be difficult. In harmony with this work, several authors elsewhere indicated that Ethiopian cultivated lands have insufficient total nitrogen due to high leaching loss, crop removal, loss of organic materials and inadequate application of N fertilizers [27,21,28].

The lowest and highest C: N ratios were recorded in land units 3 and 4, respectively (Table 3). The C: N ratios recorded in this study are generally narrower than those reported as favorable for crop production in most Ethiopian soils, which were in the range of 8: 1 to 12: 1 [17]. The narrow level of C: N ratios in the study area might be associated with low levels of fresh organic materials incorporated in to the soil under a continued removal of crop residues and cow dung and the fact that the presence of very rapid oxidation and mineralization of already existing organic materials. This is in conformity with the finding of [29,23]. Moreover, [30]

recorded low C: N ratios (respectively 4.6 and 7.7) from the top 20 cm cultivated and grass land soils of Hirni Watershed and its adjacent Agro Ecosystem in Northern Ethiopia.

### 3.5 Available Phosphorus

Differences among the land units did not significantly ( $P > 0.05$ ) affect Olson available P (Table 3). However, numerical variations were observed among the land units. For instance, relatively lower ( $17.92 \text{ mg kg}^{-1}$ ) and higher ( $23.02 \text{ mg kg}^{-1}$ ) contents of available P were recorded in soils of land units 1 and 3, respectively. The relatively higher available P of land unit 3 could be associated with the high application of DAP fertilizer for wheat based cropping pattern. According to the soil available P rating suggested by [31], all the land units under the Watershed were high in their content of Olsen available phosphorus.

Even if the OM content of the studied soils was in the range of low, its available P was found above the critical value ( $8 \text{ mg kg}^{-1}$ ) outlined by [20]. The result is supported by the finding of [28] who concluded that available P content of tropical soils did not necessarily decrease with decrease of organic matter and vice versa, indicating that organic matter is not necessarily the primary P supplying source in tropical soils. However, [32] indicated that associated with low content of OM, available P in the plough layer of almost all the soils collected from different sites in Northwestern Zone of Tigray was found to be lower than the critical level recommended by [20].

The high P concentration in the study area soils might be due to the preferred ranges of soil pH (5.7-6.8). Mineral weathering could have considerable importance for the high content of available P in the studied soils. In addition to this, the residual effect of P containing fertilizer (DAP) might have contribution for the high level of available P in the cultivated lands. This result is in accordance with the findings of [33,30].

### 3.6 Exchangeable Bases

Exchangeable bases were significantly ( $P < 0.05$ ) affected by the land units. The significant differences of exchangeable basic cations among the top soils of the land units reflect the presence of differences in slope gradient and management practices. The presence of

significant differences in clay content of the soil particle size distribution (Table 2) among the land units might also be an important reason for the variations of exchangeable basic cations. Similarly, [34] suggested that variations in the distribution of exchangeable bases depends on particles size distribution, degree of weathering, soil management practices, the intensity of cultivation and the parent material from which the soil is formed.

The minimum and maximum exchangeable Ca were observed on land units 3 and 2 with values of  $9.05$  and  $32.91 \text{ cmol (+) kg}^{-1}$ , respectively. According to the rating of [1], soils under land unit, 3 and 7 were rated as medium and high, in that order. While all the other land units of the study area were rated as very high. In line with soil fertility, a critical concentration of  $0.2 \text{ cmol(+)} \text{ kg}^{-1}$  exchangeable Ca is required for tropical soils [22]. Accordingly, the results of this study indicate that soils under all land units had more Ca concentrations than the critical level. This implies that exchangeable Ca is not a limiting factor in the soils of the study area and the soils under the study area would not require an application of Ca fertilizer as an external input.

The lowest and highest values of exchangeable Mg were recorded under soils of land unit 3 ( $1.45 \text{ cmol(+)} \text{ kg}^{-1}$ ) and land unit 2 ( $4.19 \text{ cmol(+)} \text{ kg}^{-1}$ ), respectively. According to [1] ratings, the studied soils under different land units of the Dawja Watershed had medium (land units 3, 6 and 7) to high (land units 1, 2, 4 and 5) Mg contents. On the whole, concentrations of Mg in all the land units of the study area were higher than the critical level of  $0.5 \text{ cmol(+)} \text{ kg}^{-1}$  which is recommended for tropical soils [22]. This implies that responses for the addition of Mg as an external input in the form of fertilizer is improbable in the present study area soils.

The exchangeable K content recorded from the grazing land unit (land unit 4) was higher than the other cultivated land units (Table 4). The relatively lower exchangeable K in cultivated land units might be due to its continuous losses with harvested plants. This result is in agreement with [35,36] but contrary to the finding of [37], who reported that concentration of exchangeable K was higher under farmland than in grazing land of Abo-Wonsho, Southern Ethiopia. The top 20 cm soils of the study area had high exchangeable K content except soils in land unit 3 that was rated as medium based on [1] rating system.

In soils where there is high removal of potassium by crop harvesting or grazing and exchangeable K levels becomes below the critical level, plants can give response to the application of potassium fertilizer [38]. However, as observed from Table 4, all investigated soils under all the land units of the study area had higher exchangeable K than the critical level ( $0.2 \text{ cmol}(+) \text{ kg}^{-1}$ ) suggested by [22]. This implies that, returns from K inputs application for crop production under this study area are less likely and its application as a form of fertilizer is not required for this time.

The relatively lowest exchangeable Na ( $0.33 \text{ cmol}(+) \text{ kg}^{-1}$ ) was observed on land unit 3, while the highest exchangeable Na ( $0.73 \text{ cmol}(+) \text{ kg}^{-1}$ ) was recorded on land unit 2 (Table 4). The contents of exchangeable Na in the studied soils were rated as medium except soils under land unit 2, which was high [1]. Based on the critical level ( $1 \text{ cmol}(+) \text{ kg}^{-1}$ ) suggested by [22], the exchangeable Na values of the surface soils were low and cannot cause alkalinity or sodicity problems.

### 3.7 Cation Exchange Capacity and Percent Base Saturation

The analysis of variance for CEC of the soils under the study area revealed significant differences ( $P < 0.01$ ) among the land units (Table 4). The minimum and maximum CEC values were recorded for land unit 3 ( $18.13 \text{ cmol}(+) \text{ kg}^{-1}$ ) and land unit 2 ( $41.87 \text{ cmol}(+) \text{ kg}^{-1}$ ), respectively. The lowest CEC in land unit 3 was in line with the relatively low clay content, under this land unit (Table 2). This is in agreement with

the finding of [39] in soils of Abobo area, Western Ethiopia. Based on the rating established by [1], land units 3 and 2 had medium and very high CEC, respectively, while all the other land units had high CEC values, which might be attributed to the high specific surface area of the clay particles. The results of the investigation revealed that soils of the study area are fertile and have high basic cation nutrient reserves for crop production.

Considering percent base saturation (PBS), significant ( $P < 0.01$ ) differences were observed among the land units. Accordingly, the PBS of the Watershed ranged from 62.3 to 92.2% for land units 3 and 2, respectively (Table 4). The variation of PBS could probably be associated with the variation of basic cations and cation exchange capacity of the soils. According to the rating recommended by [22], the percent base saturation (PBS) of the surface soils in all land units was rated as high, which indicates the generally base-rich nature of the soils of the study area and less vulnerability of soils to leaching in the Watershed.

### 3.8 Micronutrients (Fe, Mn, Zn and Cu)

Analysis of variance for four micronutrients (Fe, Mn, Zn and Cu) showed the significant differences ( $P < 0.01$ ) among the land units (Table 5). The probable reason for the differences of micronutrients among the land units might be the differences of land unit slope gradient and management practices that can influence the soil OM, soil reaction, texture and CEC content by which availability of micronutrients could vary from place to place.

**Table 4. Exchangeable bases and cation exchange capacity of Dawja Watershed soils under different land units**

LU	Exchangeable bases and CEC					PBS (%)
	K	Na	Ca	Mg	CEC	
	----- $\text{cmol}(+) \text{ kg}^{-1}$ -----					
1	0.62 <sup>c</sup>	0.44 <sup>bc</sup>	23.16 <sup>cd</sup>	3.82 <sup>ab</sup>	38.27 <sup>ab</sup>	73.30 <sup>c</sup>
2	0.78 <sup>b</sup>	0.73 <sup>a</sup>	32.91 <sup>a</sup>	4.19 <sup>a</sup>	41.87 <sup>a</sup>	92.20 <sup>a</sup>
3	0.46 <sup>d</sup>	0.33 <sup>c</sup>	9.05 <sup>f</sup>	1.45 <sup>d</sup>	18.13 <sup>d</sup>	62.30 <sup>d</sup>
4	0.91 <sup>a</sup>	0.66 <sup>ab</sup>	20.76 <sup>d</sup>	3.80 <sup>ab</sup>	32.93 <sup>bc</sup>	78.83 <sup>b</sup>
5	0.67 <sup>bc</sup>	0.44 <sup>bc</sup>	28.76 <sup>ab</sup>	3.02 <sup>bc</sup>	37.07 <sup>ab</sup>	88.72 <sup>a</sup>
6	0.62 <sup>c</sup>	0.43 <sup>c</sup>	26.42 <sup>bc</sup>	2.88 <sup>bc</sup>	33.60 <sup>bc</sup>	90.19 <sup>a</sup>
7	0.62 <sup>c</sup>	0.44 <sup>bc</sup>	16.44 <sup>e</sup>	2.54 <sup>c</sup>	31.33 <sup>c</sup>	63.95 <sup>d</sup>
LSD (0.05)	0.13	0.21	4.20	0.91	5.09	4.32
SE ( $\pm$ )	0.04	0.07	1.36	0.30	1.65	1.40
CV (%)	11.21	23.41	10.48	16.58	8.58	3.10
Critical level	0.2-0.6	< 1	0.2	0.5	-	60

**Table 5. Selected DTPA extractable soil micronutrients under different land units**

LU	Micronutrients			
	Fe	Mn	Zn	Cu
	-----mg kg <sup>-1</sup> -----			
1	15.21 <sup>b</sup>	29.33 <sup>b</sup>	1.58 <sup>cd</sup>	1.29 <sup>d</sup>
2	9.38 <sup>d</sup>	24.43 <sup>c</sup>	3.09 <sup>a</sup>	1.77 <sup>bc</sup>
3	19.48 <sup>a</sup>	37.29 <sup>a</sup>	2.17 <sup>bc</sup>	1.21 <sup>d</sup>
4	13.44 <sup>bc</sup>	25.14 <sup>bc</sup>	2.37 <sup>b</sup>	2.34 <sup>a</sup>
5	10.31 <sup>cd</sup>	18.82 <sup>d</sup>	1.44 <sup>d</sup>	1.40 <sup>cd</sup>
6	11.88 <sup>bcd</sup>	22.79 <sup>cd</sup>	1.54 <sup>cd</sup>	1.52 <sup>bcd</sup>
7	12.71 <sup>bcd</sup>	18.59 <sup>d</sup>	1.75 <sup>bcd</sup>	1.81 <sup>b</sup>
LSD (0.05)	3.21	4.34	0.61	0.38
SE (±)	1.04	1.41	0.20	0.12
CV (%)	13.67	9.69	17.20	13.16
Critical level	2.6-4.5	1	0.6-1	0.4-0.6

The availability of micronutrients to plants is influenced by several soil and environmental factors including management practices [40,41].

DTPA extractable Fe contents of the study area soils ranged from 9.38 mg kg<sup>-1</sup> in land unit 2 to 19.48 mg kg<sup>-1</sup> in land unit 3. Considering 4.5 mg kg<sup>-1</sup> DTPA extractable Fe as a maximum critical level [14], Fe was sufficient in all land units and it was found within the range of threshold level (4.5 to 20 mg kg<sup>-1</sup>). The result is in accordance with the previous studies in Ethiopia indicating that Fe deficiencies are not common except those reported in some studies such as [42,43].

The DTPA extractable Mn contents of the soils of the study area ranged from 18.59 to 37.29 mg kg<sup>-1</sup>. Based on [14] rating, 1 mg kg<sup>-1</sup> is critical level for Mn deficiency, thus all land units of the study area were categorized under sufficient in available manganese. This value is within the adequate range for most of the crops; since the threshold level of soil DTPA extractable Mn is 1 to 48 mg kg<sup>-1</sup> and toxicity of Mn exist only when its value exceeds 48 mg kg<sup>-1</sup> [44].

The minimum 1.44 mg kg<sup>-1</sup> available Zn was recorded for land unit 5, while maximum of 3.09 mg kg<sup>-1</sup> available Zn was recorded for land unit 2. On the other hand, the lowest (1.21 mg kg<sup>-1</sup>) and the highest (2.34 mg kg<sup>-1</sup>) available Cu were observed on land units 3 and 4, respectively. From the analytical result of Zn (Table 5) and referring to the critical level for Zn (0.6-1 mg kg<sup>-1</sup>) which is developed by [14], all soils under each land units had sufficient available Zn content. In conformity with this, [45] reported sufficient level of Zn (0.65 to 1.27 mg kg<sup>-1</sup>) in soil samples collected from Abaya Chamo Lake Basin,

Southwest Ethiopia. However, the investigation made by [43] in the Vertisols of the central highlands of Ethiopia showed the deficiency of Zn (0.4 to 0.5 mg kg<sup>-1</sup>).

Similar to the other micronutrients (Fe, Mn and Zn), available Cu contents were greater than the maximum critical level of 0.6 mg kg<sup>-1</sup> [14] and indicate that deficiency of Cu is unlikely for crop production in the study area. This is in agreement with the finding of [43] and [45] who used the same critical level and reported that all the samples collected from the Vertisols of central highlands (1.1 to 2.1 mg kg<sup>-1</sup>) and Abaya Chamo Lake Basin, Southwest of Ethiopia (0.50 to 1.75 mg kg<sup>-1</sup>), respectively were sufficient in Cu.

The DTPA extractable micronutrients were found to be in the order Mn > Fe > Zn > Cu in almost all land units of the study area. This is in agreement with the findings of [46] in soil samples from 32 locations across Ethiopia and [36] in soils of Maybar areas of South Wello Zone. Contrary to this, [45] reported that concentration of the DTPA extractable micronutrients for surface soils of Abaya Chamo Lake Basin was found to be in the order of Fe > Mn > Zn > Cu.

All micronutrients except Molybdenum become more available in low pH soil conditions. As a result, the deficiencies of Fe, Mn, Zn and Cu are unlikely to occur in soils with pH < 7 [22]. The present study is also in consent with the report of [22] and indicates that all the investigated micronutrients were found in sufficient amount. Therefore, deficiency or toxicity of these nutrients might not be expected for soils of all the land units.

#### 4. CONCLUSIONS

Slope gradient and/or management practices are probable reasons for the variation of physical and chemical fertility parameters from place to place, as those were the case in the present study area. The soils of Dawja Watershed had good physical fertility status and pH range, where most nutrients are easily available for satisfactory crop production. The soils had sufficient available phosphorus, potassium, CEC, PBS and available micronutrients. However, soil organic matter and total nitrogen are low and medium, respectively.

Therefore, the soil fertility management should focus on improving and maintaining organic matter and nitrogen levels of the soils. In order to increase soil OM and total N content, farmers should practice crop rotation like cereal-pulse crop based and minimize removal of crop residues and animal manures. Besides, farmers should exercise integrated soil fertility management, such as combining organic and inorganic fertilizer application.

Since the critical levels that were used in the comparisons were not established in Ethiopia, calibration of the soil nutrients content with crops grown in the area is required to identify the most sufficient and deficient nutrients in Ethiopia in general and the study area in particular.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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