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Assessment and mapping of status and spatial distribution of soil macronutrients in kambata tembaro zone, southern Ethiopia

Abstract

The lack of site specific fertilizer recommendation to replenish declining soil fertility has been the major challenge to boost crop production in Ethiopia. Therefore, an investigation was conducted on soil macronutrient status of Kedida Gamela, Kechabra and Damboya worded as of Ethiopia. Four hundred sixty three geo–referenced soil samples were collected by using grid survey method. phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg) were extracted by using Mehlich–III extraction method. Soil reaction was determined by pH meter. Total nitrogen (TN), Organic carbon and cation exchange capacity were predicted from Mid Infrared Spectra. The fertility maps and predication were prepared by ordinary kriging. Calcium showed strong spatial dependence but the spatial dependence of pH, OM, TN and K was moderate whereas the spatial dependence of P, S and Mg was weak. The pH of the soil samples ranged from 4.5 to 8.6 and about 83.5% of all agricultural soils were acidic in reaction. The measured EC values ranged from 0.02 to 0.81dSm–1. Available P ranged from 0 to 267ppm. Available S ranged between 3 and 63ppm and nearly 98% of the agricultural soils of the study areas had below optimum sulphur values. The TN content ranged between 0.0003% and 0.51% and about 61% of analyzed soil samples were below optimum level in TN status. The soil OM ranged from 0.0003 to 7.35%. The exchangeable K, Ca and Mg values ranged from 0.39 to 4.24, 4.9 to 19.5 and 0.68 to 6.09cmolc kg–1, respectively. The proper rate of limes for acidic soil of the study area and P, N and S fertilizers should be applied to boost the agricultural productivity. Further correlation and calibration of soil test data with plant response is reconsidered.

Keywords: available P, available S, critical levels, exchangeable cations, ordinary kriging, spatial dependence, semivariogram, total nitrogen

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Introduction

Most of sub–Saharan Africa (SSA) soils are naturally less fertile than soils of North America, Europe, and Asia. They are typically low in available nitrogen (N), CEC, soil organic matter (SOM) and commonly deficient in phosphorus (P), sulphur (S) and magnesium (Mg).[1] Therefore, soil fertility constraints to crop production in region are recognized as the major obstacles to food security.[2] Also, soil fertility is declining particularly in densely populated and hilly countries of the Rift Valley areas such as Ethiopia, Kenya, Rwanda and Malawi.[3,4] In Ethiopia, the depletion rate of macronutrients N, P and k were 122, 13 and 82kg ha–1 year–1, respectively which estimated to be the highest in SSA.[5] Ethiopia has potentially rich land resources but agricultural productivity has been below optimum yield mainly due to a range of factors including soil erosion, acidity and nutrient depletion, lack of soil fertility replenishment, nutrient mining and lack of balanced fertilization.[6–8] Crop yield tends to decrease when soil gets depleted in its nutrients.[9] The problems might be more in the case of the Southern Nations, Nationalities and Peoples' Regional State (SNNPRS) due to high population density and fragmented farm land as well as continues farming.

The proper rates of plant nutrients can be determined by knowledge about the nutrient requirement of the crop and supplying power of the soil.[9] However, Ethiopian farmers used to apply only chemical fertilizers di–ammonium phosphate (DAP) and urea to increase crop yields for about five decades and this did not consider soil fertility

status and crop requirement. For instance, in southern Ethiopia, farmers apply 100/50 kg ha–1 DAP/Urea for maize irrespective of the heterogeneity of the farm areas. In contrast to this, Flowe et al.,[10] Santr et al.,[11] Tegbaru,[12] Fanuel,[13] & Okubay et al.,[14] reported that agricultural fields are not homogenous and soil macro nutrient status is highly variable. In addition to this, DAP and urea supply only P and N but not other nutrients such as K. The omission of K from the fertilizer package was due to that when the fertilizer was tested (45years ago) at the national fertilizer demonstration, Ministry of Agriculture and the Food and Agriculture Organization of the UN, no consistent trend was observed. In addition, a soil fertility survey conducted by Murphy,[15] found no K deficiency in Ethiopian soils. However, Abiye et al.,[16] and Wassie et al.,[17] reported the deficiency of K in some Ethiopian soils. Moreover, the soil fertility mapping project in Ethiopia reported the deficiency of K, S, Zn, B and Cu in addition to N and P in major Ethiopian soils and thus recommend application of customized and balanced fertilizers.[18,19] Moreover, Mulugeta et al.,[20] Tegbaru,[12] Fanuel[13] & Habtaumu et al.,[21] reported that S content in the soils they studied were found to be very low in some Ethiopian soils.

Describing the spatial variability across a field was difficult until new technologies such as Global Positioning Systems (GPS) and Geographic Information Systems (GIS) were introduced. GIS is a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data.[22] GIS can be used in producing soil fertility map of an area that helps to understand the status of soil fertility spatially and temporally, which will help in formulating

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site–specific balanced fertilizer recommendation. These technologies allow mapping fields accurately and computing complex spatial relationships between soil fertility factors. Numerous studies have been conducted based on geo–statistical analysis to characterize the spatial variability of different properties.[23–28] Thus, information on spatial variability of soil nutrients is important for sustainable management of soil fertility. Among many Geo–statistical methods, ordinary krining is widely used to map spatial variation of soil fertility. According Ismaili Samira et al.,[29] the ordinary kriging (using either exponential or spherical models) is more accurate for predicting the spatial patterns of the soil properties pH, OM, P, and K than the two other methods (IDW and splines), because it provides a higher level of prediction accuracy.[30] Soil testing provides information regarding nutrient availability in soils which forms the basis for the fertilizer recommendations for optimizing crop yields. Soil fertility maps are meant for highlighting the nutrient needs, based on fertility status of soils and adverse soil conditions which need improvement to realize good crop yields.[31] Currently in Ethiopia, Ethiopian Soil Information System (EthioSIS) completed the fertility mapping and fertilizer recommendation work for the majority of the country's agricultural land.[19]

Knowledge about an up–to–date status of soil macronutrients at different landscapes and mapping their spatial distribution play a vital role in site–specific fertilizer recommendation to enhance production and productivity of the agricultural sector on sustainable basis. However, information on the status and spatial distribution of soil macronutrients are limited for Kambata Tembaro (KT) zone. Therefore, as part of the national initiative, this study was conducted with specific objectives to assess and map the status and spatial distribution of soil macronutrients for Kedida Gamela, Kacha Bira and Damboya woredas of KT zone. The results of this study are expected to add value to the up–to–date scientific documentation of the status of soil fertility for national soil atlas which is being considered the recommended fertilizer source for maximizing crop yields and further to maintain the sustainable agriculture .

Materials and methods

Descriptions of study areas

Location

This study was conducted in three selected woredas of KT Zone namely Damboya, Kecha Bira, and Kedida Gamela. Kembata and Tembaro is one of the zones of SNNPRS in Ethiopia. Geographically, the study area is situated at 7.12˚ to 7.42˚ latitude and 37.44˚ to 38˚ longitude and is situated approximately 250km south□west of Addis Ababa. The whole KT zone is situated between 1500 and 3500meters above sea level (masl), and the topography characterized by steep slope at the foot of Anbericho, Dato and Ketta mountains and valley sides to Holagaba Zato peasant association. However, the study areas are situated between 1689 and 2637m.a.s.l.

Land use and vegetation

Mixed crop–livestock system is the main land use system in the studied area. The major food crops grown are maize (*Zea mays L*,), teff (*Eragrostic tef Zucc*. Trotter), wheat (*Triticum aestivum* L.), enset (*Ensete ventricosum*), barley (Hordeum vulagare L.) sorghum (*Sorghum biocolor L.*) potato (Salantum tuberosum), faba beans, (Vicia faba), field peas (Pisum stivum), millet (Elevsine coracana) and other cereal crops and vegetables. Coffee (coffee Arabic) and

chat (Catha edulis Forsk) are the dominant non–food cash crops. Agriculture is entirely rain fed. There are different types of natural vegetation in the grazing and arable land. However, eucalyptus trees are replacing indigenous natural trees. In addition, there are different grass species such as elephant grasses covering the ground on the grazing lands especially in strongly sloping plain and hilly slope areas.

Soil sample collection

Surface soil samples were collected through composite sampling technique where sampling points were determined by setting pre–defined sampling points according to EthioSIS.[18] Samples were taken from locations having similar soil types, topography and similar land use history or land utilization type (LUT). Based on the topography and soil variability, 156, 149 and 155 composite soil samples were collected from March to October, 2014. The soil sampling depth was 0–20cm for annual crops and 0–50cm for perennial crops. For all soil types, 10 subsamples were collected at 15 meters distance and among each, sub–sampling points in a circle method were collected and composited. For each main sampling point, about 1kg of representative composite soil samples was collected and logged into properly labeled plastic sample bag. Soil samples were not taken from restricted areas such as animal dung accumulation places, poorly drained, recently fertilized and any other places that cannot give representative soil samples. During soil sampling, data of spatial information (latitude and longitude), topography, slope, site, land use type, crop type, local soil name, sampling depth, soil color, and crop residue management, history of fertilizer application, rate and type were recorded on site description sheet for each plot.

Sample preparation and soil laboratory analysis

The collected soil samples were air–dried, ground and passed through a 2mm sieves and 0.5mm sieve for analysis using conventional laboratory methods and spectral methods, respectively. Selected soil physical and chemical properties were analyzed at the National Soil Testing Center (NSTC) in Addis Ababa and at Yara International Soil Laboratory in London.

Soil pH and electrical conductivity (EC) were determined in H_2O (1:2) using digital pH meter with glass electrode and conductivity meter, respectively.[32] Exchangeable acidity was determined by leaching the soils by neutral 1N potassium chloride (KCl) solution, for samples with pH value less than or equal to 5.5 following the procedure of Van Reeuwijk.[32] Available S and P and exchangeable basic cations (Ca, Mg, Na and K) of the soils were extracted by Mehlich–III multi–nutrient extraction method[33] and were measured with their respective wave length range by Inductively Coupled Plasma Optical Emission Spectrometer (ICP–OES) at Yara International Soil Laboratory in London. Organic carbon, total nitrogen and CEC were predicted from MIR spectra of soil samples. Soil organic matter (SOM) was estimated by multiplying the soil organic carbon by 1.72.[33–35] The different values for the various soil fertility parameters were rated using the EthioSIS critical levels[18] as shown in Table 1.

Soil fertility mapping

Ordinary kriging was used to predict unknown values of soil nutrients concentration for non–sampled areas based on the nearby surveyed data. Point data of selective soil attributes were interpolated across the study area using the geo–statistical model and their spatial prediction were evaluated. For every soil property the experimental variogram was calculated. Among the exponential, spherical and

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Gaussian models, the best fitted model to these experimental variograms were chosen using the lowest RMSE. Mapping of predicted soil nutrients were carried out by using Arc GIS software version 10. After kriging was carried out for selective soil parameters and macronutrients, their classes were defined as very low, low, optimum, high and very high classes from the map based on the EthioSIS critical levels and other appropriate methods. The spatial dependence between samples was also determined by considering the relationship between the nugget effect (C_0) and sill (C_0+C_1) expressed in percentage: 0–25% high, 25–75% medium and 75–100% low spatial dependence between samples, as proposed by Cambardella et al.[36]

Table 1 Critical levels used for classifying soil fertility parameters analysis result (Ethiosis team analysis, 2014)

Soil parameter	Status	Critical pevel	Soil parameter	Status	Critical level
	Strongly acidic	<5.5		Very low	<0.2
	Moderately acidic	5.6-6.5		Low	2.0–3.0
Soil pH(water)	Neutral	6.6-7.3	Organic matter (%)	Optimum	3.0–7.0
	Moderately alkaline	7.3-8.4		High	7.0–8.0
	Strongly alkaline	>8.4		Very high	> 8.0
EC	Salt free	< 2	Available P	Very low	0-15
(mScm^{-1})	Very slightly	2–4	(mg/kg)	Low	15-30
	saline	4–8		Optimum	30-80
	Slightly saline	8–16		High	80-150
	Moderately saline	> 16		Very high	>150
	Strongly saline				
Total	Very low	< 0.1	Exchangeable K	Very low	< 90
Nitrogen (%)	Low	0.1–0.5	(mg/kg)	Low	90–190
	Optimum	0.15–0.3		Optimum	190–600
	High	0.3–0.5		High	600–900
	Very high	> 0.5		Very high	> 900
	Very low	< 30		Very low	< 8
	Low	30–50		Low	8–10
Ca saturation %	Optimum	50–70	Mg saturation %	Optimum	10–18
	High	70–80		High	18–25
	Very high	> 80		Very high	> 25
	Very low	< 10			
	Low	10–20			
Available S	Optimum	20–80			
	High	80–100			
	Very high	> 100			

Sources: Ethiosis team analysis.[18]

Results and discussion

Soil reaction (pH), electrical conductivity (EC) and exchangeable acidity

The pH values of the agricultural soils of Kedida Gamela, Kecha Bira and Damboya woredas varied from 4.6 to 8.2, 5 to 8.5 and 5.1 to 8.5, respectively, indicating wide range of variation from strongly acidic to moderately alkaline. The mean values were found to be 6.32, 5.93 and 6.22 for Kedida Gamela, Kecha Bira and Damboya woredas,

respectively and showed significant differences among the woredas (P<0.001) (Table 2). This variation might be due to the difference in parent material, topographic position, land use type, degree of removal of basic cations by crop harvest, and prevailing micro–climate condition like rainfall intensity.

According to EthioSIS critical levels for soil reaction,[18] 10.9, 53.85, 28.85 and 6.4% of the samples in the Kedida Gamela woreda were found to be strongly acidic, moderately acidic, neutral and moderately alkaline , respectively. Similarly, in Kacha Bira woreda,

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about 23.81, 61.22, 14,3 and 0.68% of the samples are classified as strongly acidic, moderately acidic, neutral and moderately alkaline, respectively, while, in Damboya woreda, about 12.26, 65.81, 16.77, 3.87 and 1.29% of the samples were found to be strongly acidic, moderately acidic, neutral, moderately alkaline and strongly alkaline, respectively.

The pH status was mapped by using co–kringing method and spherical model provided the best fit for the semivariogram of soil pH. In agreement with the result of this study, Cambardella et al.[36] Nourzadeh et al.,[37] Tesfahunegn et al.,[7] & Fanuel[13] reported that spherical model is the best fit for prediction of soil pH. The measured soil pH showed range value 1003m which is greater than average sampling distance (750m), implying that sampling interval in this study was adequate to capture the spatial variability in soil pH. The nugget to sill ratio which is calculated from semivariogram was 0.41 which revealed the moderate spatial dependence of soil pH (Table 2). According to Behera et al.,[38] moderate spatial dependence is due to both intrinsic and extrinsic factors. The area calculated from the predicted map Figure 1 shows that 4,678.26 ha (3.63%), 102,899.70ha (79.89%), 21,149.22 ha (16.42%) and 77.67 ha (0.05%) of study area was found to be strongly acidic, moderately acidic, neutral and moderately alkaline, respectively as the EthioSIS rating for Ethiopian soils.[18]

It was found that most of the soil samples analyzed were acidic (strongly and moderately) in reaction. Major strongly acidic soils are found in the highest altitude zones of Kedida Gamela and Kecha Bira worded as (Figure 1). Among possible reasons for this is moderate leaching of exchangeable bases, acidic parent material, decomposition of OM, harvesting of high yielding crops. The results of this study agrees with that of Abayneh et al.[39] & Mohammed et al.,[40] who reported that soils in high altitude and higher slopes had low pH values, probably suggesting the washing out of basic cations from these parts. Similarly, Hartemink,[41] Khanet al.,[42] Abreha et al.[43] & Yihenew et al.[44] reported that continuous cultivation practices, excessive precipitation and steepness of topography could be some of the factors responsible for the reduction of soil pH at the middle and upper elevations. Gebeyaw[9] has also reported that a lower pH value in cultivated land was attributed to a high rate of organic matter oxidation. This is important to produce organic acids and provide H+ to the soil solution, and thereby reduces soil pH values. This explanation was also supported by Butros et al.[45] Most plants and soil organisms prefer pH range between 6.0 and 7.5.[46–49] About 43% of soils in the current study were out of this range. Under such range, the availability of essential nutrients is critically affected. Therefore, the raising of soil pH through acid soil rehabilitation practices such as limning is crucial to boost the production and productivity of agriculture in the study areas.

Electrical conductivity (EC) of the agricultural soils of Kedida Gamela, Kecha Bira and Damboya woredas ranged from 0.036 to 0.81dSm⁻¹, 0.018 to 0.392dSm⁻¹ and 0.02 to 0.450dSm⁻¹, respectively and have the mean values of 0.16, 0.097 and 0.125 which show statistically significance difference among woredas (P<0.001) (Table 2). According to EthioSIS,[18] all of the soil samples analyzed are salt free. In line with this study, Brady[50] & Landon,[51] reported that soils of sub–humid tropics where there is sufficient rainfall to flush out base forming cations from the root zone, EC is found to be too low, usually being less than 4dS/m. Hence, plants growing in these areas do not have the problem of absorbing water because of the lower osmotic

effect of dissolved salt contents. However, according to Gomes and Garcia,[52] CV value for all woredas soils was found to be very high (>30%) indicating wide variability in EC values.

Exchangeable acidity (Hp) was determined for 78 soil samples, which have pH less than or equals to 5.5. This accounts for about 16.86% of the soil samples collected. It ranged from 0.123 to 1.67cmol (+) kg⁻¹ with a mean of 0.430cmol (+) kg⁻¹ in Kedida Gamela soils, 0.05 to 2.85cmol (+) kg⁻¹ with a mean of 0.71cmol (+) kg in Kecha Bira and 0.03 to 0.98cmol (+) kg⁻¹ with a mean of 0.24cmol (+) kg in Damboya woredas agricultural soils (Table 2). The highest exchangeable acidity value was recorded from tef cultivated field with undulating topography of Kacha Bira woreda. This may be due to the continuous application of N fertilizers (urea) without liming tef farms of acidic soils which could release H+ through nitrification process.[53] There was a negative and significant relationship between the exchangeable acidity and pH with correlation coefficient value of r =– 0.41. Abreha et al.,[42] Tegbaru et al.,[12] also reported similar findings on Ethiopian soils.

Available phosphorus

Melich–III extracted available phosphorus content varied from 1.0 to 209.0ppm, 1.0 to 74.0ppm and 0.0 to 267ppm for Kedida Gamela, Kacha Bira and Damboya woredas, respectively. This indicates that the soils of study woredas showed a wide range of variability in P status and the result is in line with that of Tekalign Mamo et al.,[54] who reported that the P status of Ethiopian highland soils were generally variable. The variability in available P contents of soils might be due to different soil management practices, specifically, inherent soil fertility status, type and rate of organic and inorganic fertilizers used in cultivated lands. Besides these factors, variation in parent material, degree of P–fixation, soil pH and slope gradient may also contribute for the difference in available P contents among agricultural soils. Also, relatively high CV values (>25%) were found, reflecting the wide variability of P status of soils in the study areas.

The mean value of available P was found to be 21.5ppm for Kedida Gamela , 6.01ppm for Kacha Bira and 15.3 for Damboya woredas ; this shows statistically significant difference between woredas (P<0.001) (Table 2). On the basis of the critical level adopted by EthioSIS[18] for Mehlich– III extractable P, 68.59%, 91.6% and 76.77% of soils of Kedida Gamela, Kacha Bira and Damiboya woredas, respectively were very low. Also, 15.38%, 6.12% and 11.61% of soils of Kedida Gamela, Kacha Bira and Damiboya woredas, respectively were low. The remaining 8.33%, 2.72% and 7.74% of soils of kedida Gamela, Kacha bira and Damiboya woredas, respectively were optimum. The high level of P was obtained for only 5.78 % and 2.59 % agricultural soils of Kedida Gamela and Damiboya woredas, respectively. The remaining 1.92 % and 0.65% of Kedida Gamela and Damiboya wordas were very high in P status. The relatively high amount of available P was observed under enset (Ensete ventricosum), framing fields. This may likely be the consequence of long–term manure and house refuse applications on enset fields. Similar findings were reported also by Alemayehu et al.,[55] & Shiferew[56] for soils in Southern Ethiopia.

The analytical data of P deviate from normality which is manifested by high skewness and kurtosis. Logarithm transformations were selected to normalize these data which showed improvement on normality of data prior to geo–statistical analysis. Then, P map was prepared by interpolation with co–krininging method. The exponential model provided the best fit for the semivariogram of soil

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available P and it was found to be better than other methods. The analytical soil P showed range values 902.5m which is greater than average sampling distance (750m), implying that sampling interval in this study was adequate to capture the variability in soil available P. The nugget to sill ratio which is calculated from semivariogram was 0.91 which implies weak spatial dependence. This may be due to soil management practices in a farmland through tillage, fertilization, crop rotation and water management.[36–58]

phosphorus map Figure 2A shows that, in terms of the area coverage, 77.86% (100,286.4ha), 20.52% (26,430.4ha) and 1.62% (2,088.ha) of the soils of the study woredas were found to be very low, low and optimum in P status as per rating of EthioSIS for Ethiopian soils.[18] This result indicates that, in general, majority (98.38%) of agricultural soils of the three woredas were deficient in P. The reasons for low P status in the soil may be due to low pH (acidic), the intensive cropping system, imbalanced use of fertilizer and nutrient mining. These finding is in line with the result of Sahlemedhin et al.,[59] who reported that P deficiency was very severe in the acidic soils of the southern, southwestern and western Ethiopia due to fixation of P with Al^{3+} and Fe^{3+}. Also, Tekalign et al.,[60] Yenenew,[61] Tekalign et al.,[62] Wakene et al.,[63] Fassil et al.,[64] Wondwosen et al.,[8] Abreha et al.,[42] Fanuel et al.,[65] Tegbaru,[12] Fanuel[13] reported that low contents of available P are a common characteristic of most of the soils in Ethiopia . Aulakh & Singh et al.,[66] reported that the low P in the soils can be due to the low organic matter. In addition to this, the P status of agricultural soils in the study areas were positively and significantly correlated with pH, r=0.25 (P<0.0001). But it negatively and significantly correlated with the clay %, r=−0.29. This may be due to domination of Al and Fe containing clay minerals that reduce the availability of P. This study indicated that P should be added in the form of organic or inorganic fertilizer to obtain optimum agricultural production in the study areas.

Available Sulphur

The available S ranged from 3.0 to 26.0ppm, 4.0 to 21.0ppm and 3 to16ppm in agricultural soils of Kedida Gamela, Kecha Bira and Damboya woredas, respectively (Table 2), where means were not significantly differ among woredas (P>0.1). According to rating of available S status by EthioSIS,[18] among agricultural soils of Kedida Gamela woreda 83.97, 14.10, and 1.92% were rated as very low, low and optimum category, respectively. Among soil samples collected from Kacha Bira woreda, 88.43, 10.2 and,1.37% were found to fall in very low, low and optimum category, respectively, whereas 85.1 and 14.19% of Damboya woreda soils were categorized very low and low, respectively.

The prediction map for S was prepared with co–krining by using Gaussian model which showed best fit for S on somevariogram after log transforming data. Range value for available S data was 2197.33 m which is far greater than average sampling distance (750m), confirming that sampling interval in this study was adequate to capture the variability in soil available S. The nugget to sill ratio was 0.78 which proves that spatial dependence of S data between samples is weak. From the map, among the soils of the three woredas, 118,365.4 ha (91.9%) and 1,0439.21ha (8.1%) were found to be very low and low, respectively (Figure 2B). Generally this finding revealed that all agricultural soils of the study areas were deficient (<20mg/Kg) in S content and likely to respond to S fertilization. This might also be one of the factors that result in lower agricultural yield in the study

woredas than national average yield per unit area. The result of this study agrees with findings of Hilette et al.[67] & Fanuel[13] who reported that S was deficient in soils collected from the different regions of Ethiopia. This might be mainly due to poor sulfur containing parent material of soil, land degradation, crop residue removal, crop uptake, low soil OM, use of non–S fertilizers (only N and P containing fertilizers used) and poor management practices. Sulfur is taken up by most grain crops in amounts similar to those of P, from 10 to 30kg/ha[68] but there has not been any practice of external addition of this nutrient in the study areas. Thus, the agricultural fields of the study areas should be supplemented by applying S rich fertilizers as required by a specific crop to boost agricultural productivity. Maintenance of the soil organic matter, utilization of subsurface inorganic S and proper management of soils should maintain the S status of the soils in the future. A positive correlation (r=0.4) was observed between organic carbon and available S component. This relationship existed because most of the part of S is associated with organic matter.[69] Tekalign et al.,[60] Solomon et al.,[70] Itanna,[71] Nand et al.[72] and Assefa et al.,[73] reported that the lower content of OM is one of the causes of lower content of S.

Total nitrogen, organic matter and C:N ratio

The descriptive statistics of TN, OM and C: N ratio is shown in Table 2. The TN status of the study area generally ranged from very low to high and was highly variable (CV>50%). Significant difference (P<0.001) in mean values was observed among the studied wored as (Table 2). According to EthioSIS,[18] among the agricultural soils of Kedida Gamela, Kecha Bira and Damboya woredas, 41.03, 20.81 and 75.16%, respectively were found to be very low in TN , 20.51, 2.68 and 11.47% of these soils, respectively were low . The remaining 35.9, 47.65 and 12.10%, respectively of the tested soils of Kedida Gamela, Kecha Bira and Damboya woreda were optimum in TN status. The only high TN values were found in 2.56 %, 28.86% and 1.27% of Kedida Gamela, Kecha Bira and Damboya agricultural soils, respectively. The prediction map for TN was prepared by interpolation with ordinary krining. The exponential model was qualified as the best fit for TN on semi variogram. Range value for TN data was 1062.5m, confirming that sampling interval in this study was adequate to capture the variability in soil TN. The nugget to sill ratio was 0.55 which proves that spatial dependence of TN data between samples is moderate. From the map, in terms of area among the soils of the three woredas agricultural land, 55,075.2 ha (46.53%), 29,591.35 (25%), 24,856.43ha (21%) and 55,631.71 (7.47%) were found to be very low, low, optimum and high, respectively (Figure 3A).

Generally, most of soils were below optimum level in TN which is in line with Desta[74] who reported that Ethiopian highlands' soils have low TN content and there was a high crop response to N fertilizers in these areas. Similarly, Tekalign et al.,[54] Eylachew[75] & Mohammed[76] reported that N is a deficient nutrient element in the soils of Ethiopia and thus called for the application of inorganic fertilizers and management of soil OM.

The lower TN in the most of the area could be as a result of cereal based continuous cropping that could be ascribed to cause rapid decomposition of OM following cultivation, lower external N inputs (like plant residues, animal manures), N (nitrate ions) leaching problem as a result of higher rainfall during summer, low amount of OM applied to the soils and complete removal of biomass from the cultivated field.[61,77,78] In order to increase the TN in the soil to

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optimum level, N in both forms of organic and inorganic fertilizers has to be applied. Similarly, the introduction of leguminous species into the cropping system by either intercropping with the leguminous crops or growing leguminous crops in rotation improves the TN of soil. The benefits of legume crops have been reported repeatedly by many authors.[79–81]

However, TN does not indicate plant–available N and is not the sum of NH4–N + NO3–N but it includes all forms of inorganic and organic soil N. Similarly, Mesfin[49] reported that analysis of soil TN alone cannot indicate sufficiency level of available N. Therefore, it is not used for fertilizer recommendations. The total nitrogen content in the soils is dependent on temperature, rainfall and altitude.[70]

The organic matter build up in soils is related to natural vegetation, cropping history and temperature.[82] Generally, the soil TN followed the pattern of soil OM distribution in all the studied soils. This is due to the fact that most of the nitrogen is in organic form and therefore becomes part of the soil organic matter.[83] Therefore, positive and strong correlation (r=0.91) was obtained between TN and soil OM. The current result agrees with that of Tuma[84] who reported that intensive and continuous cultivation forced oxidation of OM and thus resulted in reduction of TN.

The organic matter (OM) content of the soils of the study area were found to be highly variable (CV>50 %) and shows high significant difference among woredas (P<0.0001) (Table 2). This wide variability or high CV is due to variation in soil management practices, landscape positions, fertilizer type and application rates as well as climatic variables such as temperature and rain fall. High spatial variability of soil OM requires a very high sampling density to get accurate estimates.[85,86] However, in this study, the range value for OM, 10512.35m, which is far greater than the average distance between samples (750m) indicates that it is enough to capture variability in soil OM. Status of OM ranged from very low to very high for Kedida Gamela and Kecha Bira woredas while it ranged from very low to optimum for Damboya woreda agricultural soils based on rating suggested by EthioSIS.[18] The prediction map for OM was prepared by interpolation with ordinary krining. The exponential model was found to be the best fit for OM on semivariogram. The nugget to sill ratio was 0.62 which confirms that spatial dependence of OM data between samples was moderate.

In terms of area coverage, 58153.97 ha (45.15 %), 38073.11ha (29.56%), and 32577.79 ha (25.29%) of agricultural lands of the study areas were found to be very low, low and optimum respectively. The majority of soils (75%) in the study areas had below optimum level OM (Figure 3B). The lower organic matter content in these soils may be attributed to the poor management practices such as complete removal of crop residues, intensive cropping which encourages oxidation reaction, lack of addition of organic fertilizer sources and rapid rate of mineralization.[14,39,55,61,87] This has led to drastic decline of crop productivity in most of the study areas. In order to boost the crop productivity, it is recommended to apply organic residues as important source of nutrient to these agricultural fields. The C: N ratio of surface soils ranged from 0.75 to 40.75 with a mean value 8.29 suggesting the studied soils have a high variability in C:N ratio(CV>50%) (Table 2). Taye et al.,[88] reported that the C:N ratio of 15:1 to 30:1 is assumed as a favorable condition because nitrogen needs are supplied with minimum oxidation of SOM. In this study 58.01% of studied soils fall in this range whereas 37.66 and 4.33% fall in narrower and wider than

the range. Generally, narrow C: N ratios suggest OM mineralization whereas wider C:N ratios indicate NO3–1 immobilization by OM decomposing microorganisms.[89]

Changeable Bases (Ca, Mg, Na and K), Cation Exchange Capacity (CEC)

The Melich–III extractable K status ranged from 0.39 to 4.24cmolc kg⁻¹, 0.29 to5.08cmolc kg⁻¹ and 0.31 to 6.05cmolc kg⁻¹ in agricultural soils of Kedida Gamela, Kecha Bira and Damboya woredas, respectively (Table 3). The mean values for the soils of Kedidada Gamela, Kecha Bira and Damboya woredas were found to be1.60, 1.12 and 1.29cmolc kg⁻¹, respectively. According to the critical level adopted by EthioSIS,[18] 0.64%, 8.84% and 4.52% of Kedida Gamela, Kecha Bira and Damiboya woredas, were low in exchangeable K status. The exchangeable K status of 48.08, 75.51 and 70.32% of Kedida Gamela, Kecha Bira and Damiboya woredas was optimum. The other 33.97%, 8.16% and 18.08% of Kedida Gamela, Kecha Bira and Damiboya woredas, was high in exchangeable K status. The remaining 17.3% of Kedida Gamela, 7.48% of Kacha Bira and 7.1% of Damboya woredas were found to be very high in available K status.

Also, Figure 4A shows the K status of non–sampled sites that were predicted from measured sites by interpolation by using co–kringing method. The Gaussian model was found to be the best fit for exchangeable K map. The range 9584.65m indicates that the sampling distance is enough to capture the variability K in the agricultural land. The sill to nugget ratio 0.52 indicates that the spatial dependence of K is moderate. It was observed that, in terms of area coverage, 60.52 %(77,952.87ha), 38.36% (49,414.92 ha) and 1.12% (1437.09 ha) of agricultural lands of three woredas were found to be optimum, high and very high, respectively (Figure 4A). In line with this result, Abay et al.,[90] reported that application of K did not significantly influence potato tuber yield and K concentrations in both leaf and tuber, exchangeable and available potassium in the soil of the study zone. On the other hand, numerous studies have proved that many Ethiopian highland Vertisols soils shown an increase in crop yield when fertilized with potash fertilizer.[16] The higher content of exchangeable K may be due to the predominance of potassium rich minerals such as mica containing minerals.[78,91]

Potassium: magnesium ratio of the studied soils were greater than 0.7.This indicates that there is no interference of Mg in K uptake (Mg induced K deficiency).[92] In contrast to this result Fanuel[13] & Hilette[67] reported lower ratio of K to Mg (less than 0.7) and hence Mg may induce K deficiency in soils of southern and central highlands of Ethiopia, respectively. Regardless of the high amount of exchangeable K and K:Mg ratio, K fertilizers should be applied to boost crop productivity since most of soils of the study areas are clay soils[93] that could fix exchangeable K and reduce its availability for plants.[19]

Exchangeable Ca²⁺ varied from 2.90 to 25.51cmolc kg⁻¹ in Kedida Gamela (with mean value of 11.44), 2.32 to18.13 in Kecha Bira (with mean value of 8.0) and 5.46 to33.24 a in Damboya (with mean value of 12.89), indicating wide variability within and among soils of the three worded as (Table 3). The spatial distribution of Ca²⁺ through the agricultural soils in the study areas is shown in Fg.3B which is mapped by interpolation with ordinary krining and spherical model was found to be the best fit for Ca²⁺. The nugget to sill ratio 0.25 shows that the spatial dependence of Ca²⁺ was strong structure. The range 928.89 m indicates that the average distance between soil samples is adequate enough to capture variability in Ca²⁺. Figure 4B

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shows that in terms of area coverage according to critical level set by FAO,[94] 323.85ha (0.25%), 35920.83ha (27.89%) and 92,555.13 ha (71.86%) of the agricultural land were found to be low, optimum, high and very high, respectively. Based on the critical values set by FAO[94] amount of exchangeable Ca was above its respective critical values in 99.75% of agricultural soils in the three woredas. The large presence of Ca^{2+} throughout the study areas could be due to the nature of the parent material.

Excangeable Mg^{2+} variedfrom 0.68 to 6.09cmolc kg⁻¹ in Kedida Gamela(with mean value of 2.16) , 0.74 to 3.94 in Kecha Bira (with mean value of 1.95) and 1.06 to 6.33 in Damboya (with mean value of 2.82) , indicating wide variability within and among soils of the three woredas (Table 3). Based on the critical values set by FAO[94] amount of exchangeable Mg^{2+} was above its respective critical values in 99.4% of soil samples collected from the three worded as (Figure 4C). In terms of area, 94.35% (12,1534.3ha) and 5.65% (7,270.59ha) was optimum and high, respectively. The range was 1152.98 m for Mg^{2+} data. Spatial dependence was weak having nugget to sill ratio 0.79.

It is stated that Mg deficiency can occur in soils with high ratio of exchangeable Ca/Mg (10:1).[95] The ratio observed in the soils studied ranged between 2.5 and 16.6 and the ratio exceeded 10 in 25.5% of soils samples collected from the three woredas. This confirmed that the Ca induced Mg deficiency in the soils of study area. Similarly, high levels of exchangeable K may also have interfered with Mg uptake by crops. In the study area, K:Mg ratio was greater than 1:1 in 90% of soil samples collected. This confirmed that K induced Mg deficiency existed in the study areas. This can be corrected by Mg application to bring the K to Mg ratio closer to 1:1 and Ca to Mg ratio 1:10.

Generally, the larger proportion (71.22–96.02%) of exchange sites of the soils of the woredas were occupied by Ca and Mg and the mean relative abundance of basic cations in the exchange complex was in order of Ca>Mg >K>Na for soils collected from the study areas. This could be related to the charge density where the divalent cations (Ca and Mg) have higher affinity towards the colloidal sites than monovalent cations (K and Na). This is in agreement with the findings of Okubay et al.,[14] Fanuel[13] & Hilette et al.,[67] who reported similar scenarios of the cations. The percentage base saturation (PBS) varied from 22.25 to 99.98% (Table 3). According to Maria and Yost,[96] about 5.5, 27.03, 45.93 and 21.5% of the areas were found to be low (20–40%), medium (40– 60%), high (60–80%) and very high (80–100%), respectively in PBS. Considering the PBS as a criteria for leaching, it may be noticed that about 1.5%, 13.19%, 44.18% and 41.10% of sampled soils were strongly leached (15–30%PBS), moderately leached (30–50% PBS), weakly leached (50–70% PBS) and very weakly leached soils (70–100% PBS), respectively.[48]

The cation exchange capacity (CEC) varied from low to very high and ranged between 5.06 and 52.9meq/100g with mean value of 21.86 for all study areas. High CV value (31.33%) indicates that the soils of the study area vary widely in CEC. This might be due to differences in soil type, land use type and soil fertility management. According to London,[97] 15.72, 56.77 25.11 and 2.4% of soil samples collected from the study area are categorized as low, moderate, high and very high, respectively in CEC, indicating that about 84.38% of the soils have adequate basic cations to support plant growth. The high value of CEC in the soils is mainly due to high clay content and the predominance of 2:1 clay minerals. Also, positive and significant correlation (r=0.37) between pH and CEC of the soil samples collected from the study area was observed. This result is in line with that of Abebe et al.,[98] Havlin et al.,[99] & Tegbaru[12] who reported similar finding.

Table 2 Descriptive and geo statistics of selected soil fertility parameters

Woreda	Descriptive statistics	pH	EC dSm⁻¹	Hp cmol kg⁻¹	P Ppm	S	OM%	TN	C:N _
KedidaGamela (N=156)	Minimum	4.6	0.036	0.123	1	3	0.0003	0.0003	0.77
	Maximum	8.2	0.81	1.67	209	26	7.35	0.51	40.75
	Mean	6.32a	0.16a	0.43b	21.59a	7.81a	2.48b	0.1137b	9.84a
	Median	6.3	0.1	0.6	8	7	2.45	0.1241	10.5
	Std Dev	0.6505	0.12	0.28	34.48	3.33	2.04	0.1041	7.53
	CV (%)	10.29	75	68.97	150. 97	42.61	82.25	89	76.52
KechaBira(N=149)	Minimum	5	0.002	0.05	0	4	0.001	0.0003	0.75
	Maximum	8.5	0.392	2.85	74	21	7.69	0.5	28.46
	Mean	5.93b	0.097c	0.75a	6.01b	7.58a	3.78a	0.2193a	8.43b
	Median	5.9	0.075	0.42	3	7	4.02	0.2476	8.47
	Std Dev	0.597	0.036	0.71	3.36	3.36	2.39	0.1317	4.38
	CV (%)	10.07	37.11	95	55.91	38.47	63.22	60.5	52.47
Damboya(N=155)	Minimum	5.1	0.02	0.03	1	3	0.0003	0.0003	0.75
	Maximum	8.5	0.45	0.98	267	16	6.45	0.3	40.5
	Mean	6.22ab	0.125b	0.24c	15.37ab	7.23a	0.88c	0.0495c	7.86C
	Median	6.1	0.106	0.14	7	6	0.0003	0.0003	0.75
	Std Dev	0.638	0.0802	0.15	2.69	2.69	1.44	0.035	7.99

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Table Continued

Woreda	Descriptive statistics	pH	EC dSm^{-1}	Hp cmol kg^{-1}	P Ppm	S	OM%	TN	C:N
	CV (%)	10.25	64	62.5	17.58	37.21	160	70.7	101.65
	Minimum	4.6	0.002	0	0	3	0.0003	0.0003	0.75
	Maximum	8.5	0.81	2.85	267	26	7.69	0.51	40.5
	Mean	6.16	0.128	0.48	14.46	7.54	2.49	0.1260b	8.29
Total (460)	Median	6.1	0.1	0.38	5	7	2.36	0.12	6.89
	Std Dev	0.62	0.097	0.48	27.6	2.99	2.31	0.125	9.67
	CV (%)	10	75.72	78.23	94.89	39.72	92	99.21	83.11
	Model	Spherical	_	_	Spherical	Gaussian	exponential	Exponential	_
	Range	1003	_	_	902.5	2197.33	10512.35	1062.5	_
	$C_0/(C_1 =+ C_0)$	0.41	_	_	0.91	0.78	0.62	0.55	_
	SD	Moderate	_	_	Weak	Weak	Moderate	Moderate	_
	F value	2.49***	18.9***	95.73***	6.86***	0.45NS	60.88***	98.05***	6.03**

N, number of total samples per woreda, SD, spatial dependence, *** =P<0,001, ** =P<0, 01, NS, non significant Means with similar letters are not statistical significant at P<0.01

Table 3 Descriptive and Geo statistics for Exchangeable Cations , CEC and present of base saturations(PBS)

Woreda	Descriptive	Ca Cmol(+)kg-1	Mg	K	Na	CEC	PBS %
KedidaGamela (N=156)	Minimum	4.9	0.68	0.39	0.07	8.45	34.75
	Maximum	19.51	6.09	4.24	2.47	42.38	99.98
	Mean	11.23b	2.16b	1.60a	0.37	21.58b	71.77
	Median	10.68	2.03	1.56	0.17	21.74	69.55
	Std Dev	3.13	0.76	0.21	0.06	5.34	15.1
	CV (%)	27.89	35.37	46.21	16	24.77	21.03
KechaBira (N=149)	Minimum	2.32	0.74	0.29	0.06	5.06	29.71
	Maximum	18.13	3.94	5.08	0.33	32	98.89
	Mean	8.70c	1.95c	1.12b	0.13	20.76b	56.95
	Median	8.52	1.88	0.93	0.11	21.74	56.55
	Std Dev	3.16	0.55	0.67	0.009	5.63	14.2
	CV (%)	36.34	28.4	59.4	7	27.1	24.92
Damboya (N=155)	Minimum	5.46	1.06	0.31	0.1	5.15	22.5
	Maximum	33.24	6.33	6.05	3.4	52.9	99.04
	Mean	12.89a	2.82a	1.29b	0.43	23.22a	73.19
	Median	11.89	2.48	1.05	0.25	22.1	71.98
	Std Dev	4.76	1.14	0.79	0.05	8.84	15.61
	CV (%)	36.89	40.68	60.9	12	38.06	21.33
Total (N=460)	Minimum	2.32	0.68	0.29	0.06	5.06	22.5
	Maximum	33.24	6.33	6.05	3.4	52.9	99.98
	Mean	11.05	2.32	1.34	0.32	21.86	67.02
	Median	10.4	2.12	1.12	0.16	21.84	66.9
	Std Dev	4.38	0.94	0.76	0.17	6.85	16.1

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Table Continued

Woreda	Descriptive	Ca Cmol(+)kg-1	Mg	K	Na	CEC	PBS %
	CV (%)	39.63	40.56	56.66	54.77	31.33	24.02
	Model	Spherical	Exponential	Gaussian	-	-	-
	Range	928.89	1152.98	9584.65	-	-	-
	$C_0/(C_1 =+ C_0)$	0.25	0.79	0.52	-	-	-
	Spatial dependence	Strong	Weak	Moderate	-	-	-
	F value	41.3.4(P<0.0001)***	40.2 (P<0.0001)***	17.47(P<0.0001)***	16.73(P<0.0001)***	8.3(P<0.001)***	43.89 (P<0.0001)***

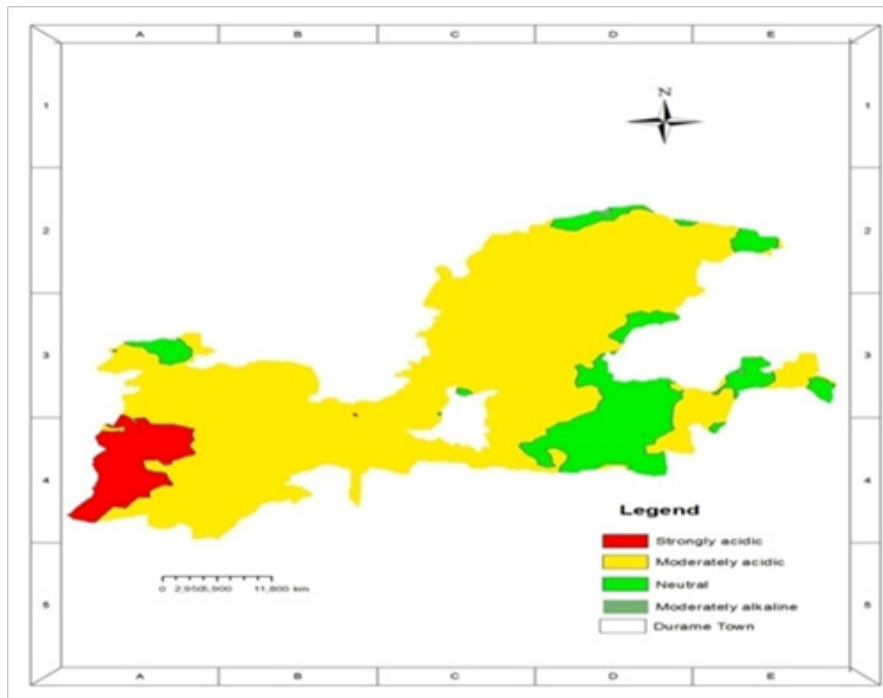Means with similar letters are not statistical significant at P<0.01

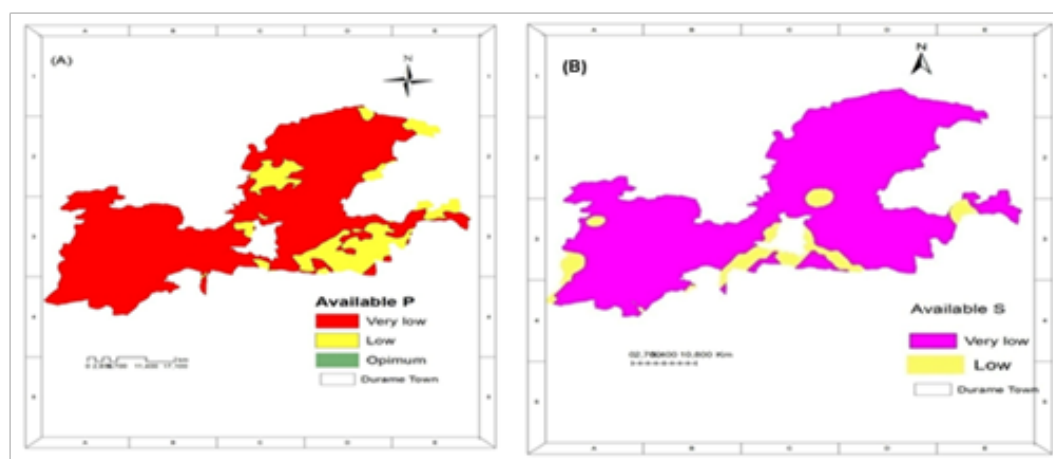**Figure 1** Soil pH map of kedida gamela, Kechabira a and Damboya woredas in Southern Ethiopia.

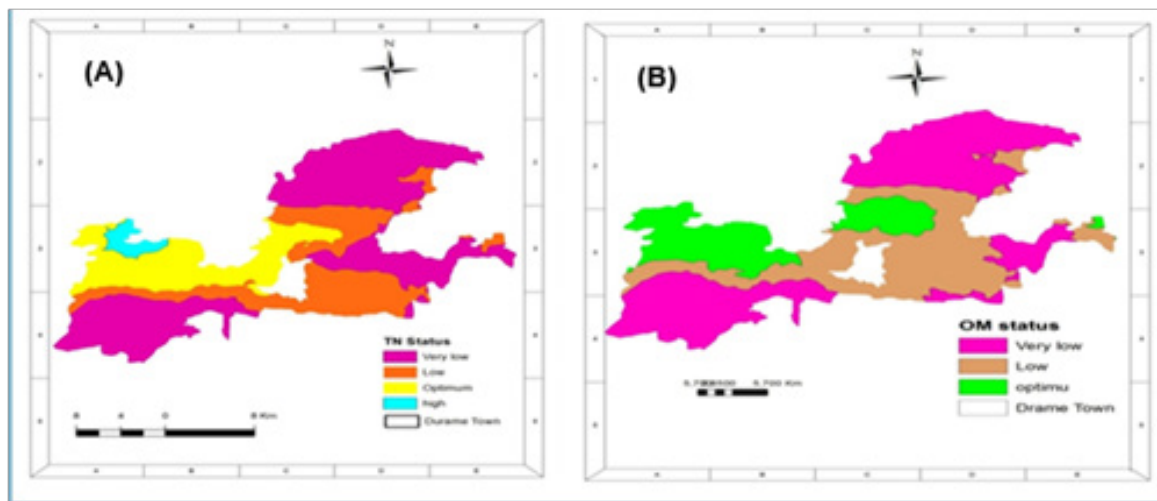**Figure 2** Soil available (A) P and (B) S map of Kedida Gamela, Kecha Bira and Damboya woredas in Southern Ethiopia.

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Figure 3 Soil (A) TN and (B) OM map of Kedida Gamla Kecha Bira Damboya woredas in Southern Ethiopia.
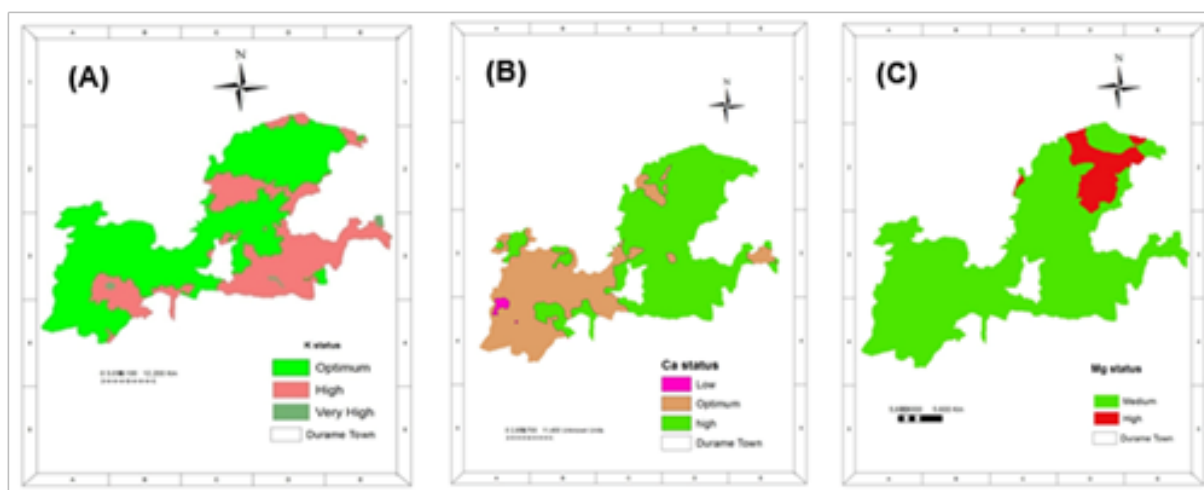

Figure 4 Exchangeable K (A) , Ca (B) and Mg (C) maps of Kedida Gamela, Kecha Bira and Damboya woredas in Sothern Ethiopia.

Conclusion and recommendations

The present study revealed that there is wide spatial variation in soil pH, EC and macronutrient status of the study woredas. All the variables studied showed spatial dependence of the variation at different scales. This observed spatial dependency can be used to support spatial sampling for detailed soil mapping in site specific soil management. For this, the optimal sampling spacing identified in this study can be used and accurate for interpolation technique such as kriging can be used for detailed mapping of the soil properties.

The pH of the soil ranged from 4.6 to 8.5, indicting wide variation with status of strongly acidic to moderately alkaline. However, 83.5% of the soils collected from the three wordas were acidic in reaction which can affect the availability and solubility of some soil nutrients such as P and thus reduce crop yields. Therefore, appropriate rate of lime needs to be applied or cultivating acid tolerant crops is recommended for both strongly acidic and moderately acidic soils of the study woredas to obtain optimum crop yields. The electrical conductivity of the soils varied from 0.02 to 0.81dSm^{-1} indicating that all the soil samples are salt free. The plant available P status ranged from 0 to 267ppm. But about 89% of the agricultural soils were below the optimum level mainly due to the acidity of the soil reaction. Thus, site specific organic or inorganic P fertilizer sources are recommended to boost the agricultural productivity of the study areas. The available S status of the study areas ranged between 3ppm and 63ppm but nearly all of the agricultural soils of the study areas were below optimum (very low and low) in available S status. Therefore, S should be the part of recommended blended or compound fertilizer. The TN ranged between 0.0003% and 0.51% and about 60% of analyzed soil samples were below optimum TN level. The exchangeable K status ranged

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from 112ppm to 2360ppm and about 96% of the analyzed soil samples were above or at optimum in exchangeable K status. However, this may not be evidence that K is not limiting nutrient in the study area due to hidden hunger. Ca and Mg were in sufficient level in all soils of the study areas but Ca: Mg ratio exceeds the critical level indicating Mg deficiency.

Finally, further correlation and calibration of soil test data with plant response is recommended for site–soil–crop specific fertilizer recommendation with appropriate rate since soil analysis alone cannot go beyond the identification of toxicity, sufficiency or deficiency level of soil nutrients due to complex and dynamic nature of the soil.

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Conflict of interest

The author declares no conflict of interest.

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