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Assessment of Soil Fertility Status in Selected Fields under Maize Production in Kongwa District, Dodoma Region, Tanzania

Daniel M. Nhunda [a*], Johnson M. Semoka [a] and Tindwa Hamisi [a]

[a] Department of Soil and Geological Sciences, College of Agriculture, Sokoine University of Agriculture, P.O. Box 3008, Morogoro, Tanzania.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study was conducted in the Kongwa District to assess the fertility status of soils of the selected fields under maize production to understand fertility variability among soils and recommend appropriate fertilizer rates. The study involved randomly selected 24 maize fields. Composite soil samples were collected in these fields at 0–20 cm deep and characterized for soil fertility status. Results indicated that 48% of the soils were sandy clay loam and 26% were sandy loam. The remaining fields had clay or loamy sand textural classes. The soil pH ranged from extremely acidic (3.52) to moderately alkaline (7.7), organic carbon ranged from very low to medium (0.19-1.60%) and total N were very low to low (0.01-0.15%). Also, results indicated that 42% of soils had P deficiency and 16.7% had inadequate S levels. In addition, 45.8% of the soils had inadequate

**Corresponding author: E-mail: nhundadaniel92@gmail.com;*

exchangeable K and exchangeable Mg levels ranged from very low to high (0.29-4.06 $cmol_{(+)}$ kg^{-1}). Exchangeable Ca was low to very high (1.06 to 10.04 $cmol_{(+)}$ kg^{-1}) with favourable base saturation for crop production. The CEC ranged from very low (2.62 $cmol_{(+)}$ kg^{-1}) to medium (18.9 $cmol_{(+)}$ kg^{-1}). Extractable micronutrients such as Cu, Fe, and Mn were adequate but Zn was inadequate in 58% of the soils. Categorizing nutrient status in soils of the study area showed that fertility is poor regarding N, P, K, Zn, Mg, and Ca. Hence, the studied soils need external nutrient inputs and proper management to optimize crop production.

Keywords: Fertilizer recommendations; maize; micronutrients; soil fertility; soil properties; Tanzania.

1. INTRODUCTION

Soil fertility is the ability of the soil to provide essential plant nutrients (N, P, K, Mg, Ca, Na, S, Fe, Cu, Mn, Zn etc.) in the available forms. The decline in soil fertility has remained one of the most important factors explaining the significant gap observed between potential and actual food production in sub-Saharan Africa [51]. It has been widely acknowledged that poor soil fertility is the principal constraint to smallholder farmers in Africa. There are number of factors that cause poor soil fertility in semi-arid regions [40] namely: cultivating continuously for many years without or with little fertilizer input use, crop removal, leaching and soil erosion. These factors have decreased the soil nutrient reserves to very low levels. Poor soil fertility occurs mainly when the mining of plant nutrients from the soil exceeds their replenishment, resulting in a negative balance of plant nutrients. It has been reported that, in all cropping systems in Tanzania, more nutrients are leaving the system than are being added [34]. Of all the plant nutrients, nitrogen (N) is commonly deficient in soils [56]. In Tanzania, annual N depletion rates ranges from 20 to 40 kg ha^{-1} [15]. Research on soil fertility assessment conducted in the Southern highlands of Tanzania showed that 77% of the studied soils had very low to low N content [22]. N is continuously lost from the soils through microbial denitrification, leaching, chemical volatilization, soil erosion and crop removal [10]. The N reserves in most agricultural soils including those in the Kongwa district must therefore be replenished to maintain an adequate level of crop production [7,11]. Phosphorus is another plant nutrient required in large quantities but usually available in limited amounts in semi-arid soils. Phosphorus (P) occurs in limited amounts because of soil erosion, losses and fixation due to high clay content and metal oxides as a result of weathering activities [21,22]. Availability of P for agricultural uptakes in semi-arid soils from P-containing fertilizers depends on the sorption capacity of the soil to hold it from losses, soil pH and metal cations [27,29,31], and the P saturation degree of the soil which determines additional P to be added to the soils and held safely with minimum losses to the environment [29]. Generally, 70- 90% of added P through fertilization in soils is fixed depending on soil characteristics, thus decreasing plant available P [4], consequently leading to high P fertilizer application rates in agricultural fields (Bekele et al., 2020). Studies have also shown that the characteristics of well-drained soils of semi-arid areas which are often old weathered and leached Ultisols or Oxisols, intensify the soil fertility problem about N, P, K and other nutrients [43]. A study by Msanya et al. (2018) in Dodoma district, Tanzania also reported low nutrient status, especially for N, P and Zn. These results concur with those found by Mkoma [36] who reported very low contents of N (0.04 -0.11%) and low P (4.17 -7.16 mg P kg^{-1}) in Kongwa and Kiteto districts. Soils in semi-arid regions have low organic content and low clay percent, all of which act as storehouses of positively charged plant nutrients such as Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} [37]. Because of low clay and organic content which are negatively charged and hence responsible for holding up the positively charged cations, soils easily lose positively charged cations through leaching, soil erosion and crop removal from the fields. Medium contents of Ca, Mg, K and Na were reported in Kiteto district, this information is concurrent with results obtained from soils of Dodoma district [37]. Plants also require micronutrients such as B, Fe, Mn, Zn and Cu although in low concentration [9,19]. The incidence of micronutrient deficiency has markedly increased in recent years due to intensive cropping, loss of top soils by erosion, through leaching, liming of acid soils, decreased use of farm yard manure compared to chemical fertilizers and use of marginal lands for crop production [45]. Factors such as pH, redox potential, biological activities, soil organic matter and clay content are important in determining micronutrients in soils [45]. The study by Msanya et al. [37] reported that soils in Dodoma central Tanzania have adequate micronutrients for crop production i.e., Fe, Mn and Cu except for Zn. These results are similar to those reported by Mowo [35] from studies conducted in the Kiteto district. Sulphur (S) is another plant nutrient that is increasingly being recognized as the fourth major limiting nutrient after N, P and K in crop production [57]. It is lost from the soils through crop uptake, burning of the vegetation cover and leaching. Chaudhary et al, (2007) reported that 1 kg of S per hectare is lost through the production of one tone of high-yielding rice variety. The study by Semoka et al. [52] also indicated that 40% of soil samples taken from five Rice growing areas in the Kilombero district had insufficient levels of S. Furthermore, Gharibu, [16] found that 100% of the twenty soil samples taken from rice producing areas in Kilombero had low levels of S.

Many research works conducted address the problem of poor soil fertility as a result of poor soil management, but little information on the status of each plant nutrient such as N, P, K, bases and micronutrients and ways to manage the soils especially, in the Kongwa district is available. In addition, no fertilizer recommendations for each of the nutrients in semi-arid zones of central Tanzania have been established [33,44,46,49,55,35,28].

The overall objectives of this study were therefore to assess soil fertility from which the status of each plant nutrient mentioned will be identified establish fertilizer recommendations and demystify ways of semi-arid soil fertility management. To achieve the main goal of the study, these were the specific objectives; analyse soils of selected fields to identify the status of plant nutrients, identify limiting nutrients from each of selected fields, group limiting nutrients into fertility groups and perform field-specific fertilizer recommendations.

2. MATERIALS AND METHODS

2.1 Description of the STUDY area

This study was conducted in selected fields of maize cropping systems in Kongwa district, the semi-arid zone of Central Tanzania. The twenty four fields were located between 6^{o}15'30" to 6^{o}19'43" S and 36^{o}37'59" to 36^{o}51'00" E. The elevation of the study area ranges from 900 to 1 000 metre above sea level (m.a.s.l.). It is on the leeward side of Mt. Ukaguru with bush or thicket type of vegetation (Fig. 1). The total annual precipitation is about 400 to 600 mm with a peak rainfall experienced in December. The mean annual temperature is 26°C. According to the World Reference Base for Soil Resources (WRB), the soils of the district are classified as Chromic Luvisols with sandy loam texture [14].

2.2 Site Selection and Soil Sampling

Four villages in Kongwa district, Dodoma region of Tanzania which are involved in maize production as main food crop were randomly selected. The selected villages are 12.7-21.9 km from one another. The villages have high heterogeneity in climatic conditions and soil characteristics. In these four villages, 24 fields were selected (Fig. 1) and a composite soil sample from each field was collected at 0-20 cm deep. The composite soil sample of each field was obtained from at least 11 spots selected in a zigzag pattern over the whole field. Each composite soil sample was about 1 kg. After sampling, all composite soil samples were transferred to the laboratory for analysis.

2.3 Laboratory Soil Analysis

Soils were subjected to laboratory analysis in the Soil Laboratory of the Sokoine University of Agriculture, in Tanzania. Organic carbon was determined by the Walkley-and Black wet oxidation method by Nelson and Sommers [53] and total nitrogen (TN) by the micro-Kjeldahl procedure of Loria et al. [26]. Available P was extracted using Bray-1 and Olsen methods of Bray and Kurtz [6] and measured by Spectrophotometer following colour developed by molybdenum blue method [39]. Exchangeable bases were extracted by ammonium acetate saturation method [54] and cation exchange capacity was determined from NH_4^+ saturated soil colloids and displaced using 1 M KCl, then determined by Kjeldahl distillation method for estimation of cation exchange capacity (CEC) of the soil [47]. Extractable sulphur ($SO4^{2-}S$) was extracted using calcium monophosphate ($Ca(H_2PO_4)_2.H_2O$), then determined by the turbidimetric method as described by Moberg [32]. The EC for soil samples from Kongwa was measured by electrode method using EC meter in a 1:2.5 soil: water (or $CaCl_2$ for pH only) extract as described by [30]. Extractable metallic micronutrients (e.g., Cu, Fe, Zn and Mn) were extracted by diethylene triamine-penta-acetic acid (DTPA) as described by Lindsay and Norvell [42]. Concentrations of Fe, Zn and Mn were determined by atomic absorption spectrophotometer. Total exchangeable bases (TEB) were calculated as the sum of exchangeable bases Ca, Mg, K and Na whereas nutrient ratios such as Ca:Mg and Mg:K were calculated from the quantities of exchangeable bases.

2.4 Identification of Limiting Nutrients and Soil Fertility Groups

Limiting nutrients for each studied field were identified after laboratory analysis of soil samples and grouped into classes according to variability and frequencies of their occurrence. Each nutrient parameter was interpreted through rating against published thresholds (e.g., low or sufficient) using the recommended critical values for rating chemical and physical soil parameters [24]. Nutrients with concentrations lower than the required concentration were considered limiting for crop production (Table 1). This was done to understand the specific nutrients that are likely to limit maize crop growth and development. Soil fertility groups were established on the basis of limiting nutrients for each field. Fields having the same limiting nutrients were placed in a particular soil fertility group. This was done in order to establish a basis for making field specific fertilizer recommendations.

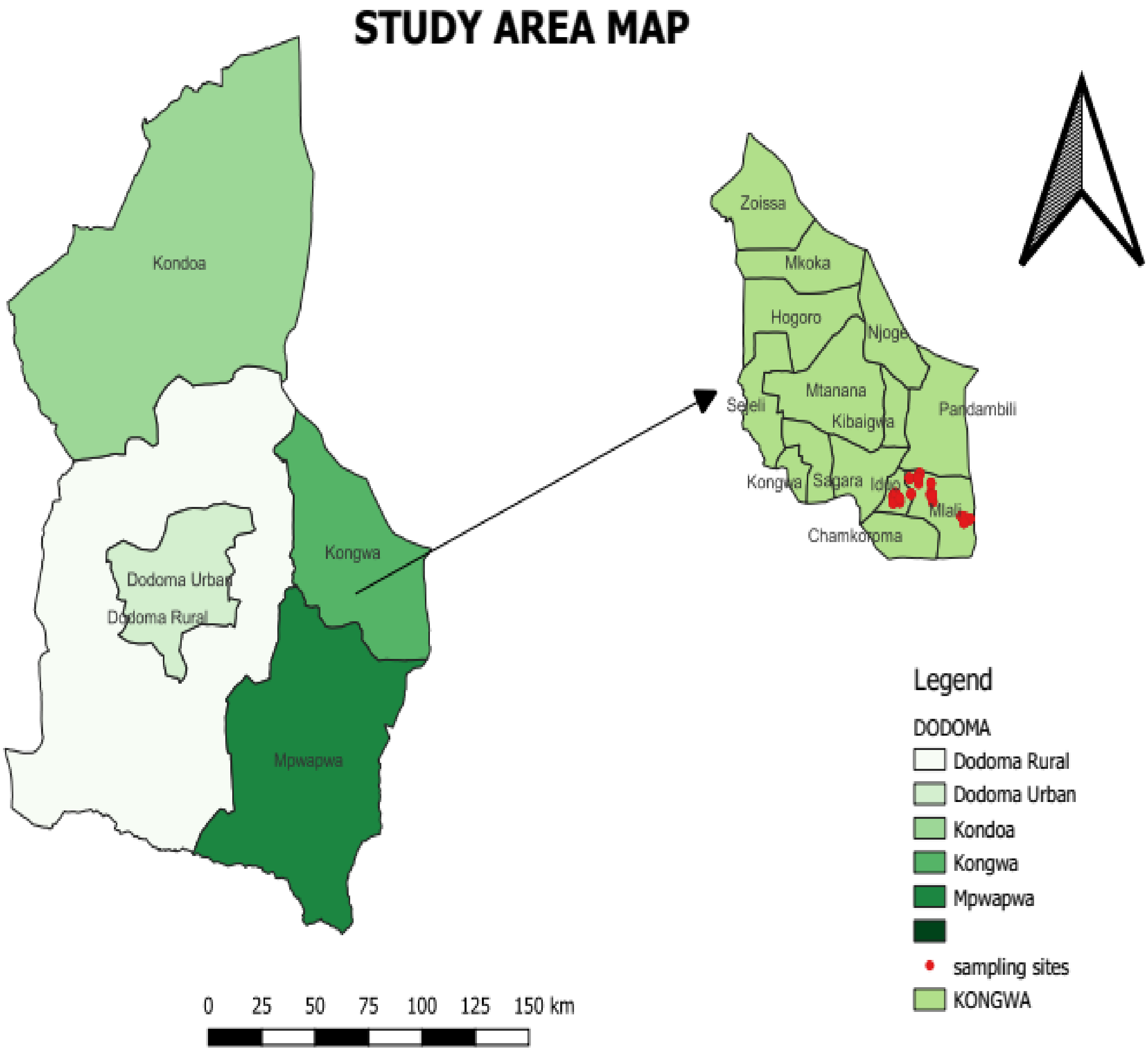

Fig. 1. Map of Kongwa District showing sampling sites in the selected villages

Table 1. General critical levels of rating some chemical parameters

Parameter	Critical value	Reference
OC (%)	2.51	Allison (1965)
TN (%)	0.50	Bremner (1965)
P (Bray-Kurtz 1)	20	Bray-Kurtz 1(1945)
P (Olsen)	10	Olsen et al., 1954
Ca (cmol$_{(+)}$ kg^{-1})	2.1	Chapman (1965)
Mg (cmol$_{(+)}$ kg^{-1})	0.7	Chapman (1965)
K (cmol$_{(+)}$ kg^{-1})	0.20	Chapman (1965)
Na (cmol$_{(+)}$ kg^{-1})	0.51	Chapman (1965)

3. RESULTS AND DISCUSSION

3.1 Physical Properties of the Soil

Physical properties of the soil determined were the particle size distribution. Data on textural classes of the studied soils are presented in Table 2.

The soil textural classes ranged from clay to sandy loam. The study area is largely dominated by sandy clay loam soils (48%) and less by sandy loam soils (26%). According to Kyveryga et al. [23], sandy clay loam and sandy loam textured soils are suitable for maize production since they are capable of holding water for relatively longer periods than other textures; they are good in infiltrating air and water and can hold nutrients. Soil texture affects absorption of nutrients, microbial activities, the infiltration and retention of water, soil aeration, tillage, and irrigation practices [15].

Table 2. Particle size distribution in selected soils of each field in four villages -Kongwa District

Village	Farm no.	Particle size distribution and textural classes			
		Clay (%)	Silt (%)	Sand (%)	Textural Class
IHANDA	1	25.4	0.92	73.68	SCL
	2	58.4	10.92	30.68	Cl
	3	13.4	2.92	83.68	LS
	4	30.4	2.64	66.96	SCL
	5	36.4	2.64	60.96	SC
	6	22.4	1.64	75.96	SCL
NGHUMBI	1	24.4	8.64	66.96	SCL
	2	17.4	1.64	80.96	SL
	3	17.4	3.64	78.96	SL
	4	25.04	13.28	61.68	SCL
	5	23.04	1.28	75.68	SCL
MLALI	1	11.04	1.28	87.68	LS
	2	17.04	3.28	79.68	SL
	3	43.04	0.28	56.68	SC
	4	37.04	1.28	61.68	SC
	5	20.04	0.28	79.68	SCL
	6	21.04	0.28	78.68	SCL
IDUO	1	17.04	0.28	82.68	SL
	2	20.04	4.28	75.68	SCL
	3	59.04	6.28	34.68	C
	4	22.04	1.28	76.68	SCL
	5	28.04	2.28	69.68	SCL
	6	55.04	3.28	41.68	C

Key: *SCL = sandy clay loam, SL = sandy loam, C= clay, LS = loamy sand*

Table 3. Soil pH, EC, total N, OC, extractable P, S and limiting nutrients in the twenty-four farmer's fields in Kongwa District –Dodoma

Village	Farm No.	Soil pH_{H2O}	EC	TN	OC	Ext.P		S	Limiting nutrients
						(Olsen)	(Bray-1)		
			(dS m^{-1})	(%)		(mg kg^{-1})			
IHANDA	1	4.81	0.055	0.01	0.19/		7.53/	3.43/	N, P and S
	2	4.23	0.077	0.1	0.93 /		12.00s	11.81s	N
	3	5.36	0.038	0.03	0.24/		5.86/	14.81s	N and P
	4	4.65	0.067	0.1	0.93 /		9.91/	20.48s	N and P
	5	3.52	0.091	0.07	0.74 /		2.80/	19.80s	N and P
	6	4.39	0.051	0.08	0.78/		2.24/	19.69s	N and P
NGHUMBI	1	7.05	0.207	0.15	1.11/	38.61s		10.33s	N
	2	7.06	0.192	0.09	1.11/	53.51s		16.72s	N
	3	7.1	0.118	0.07	0.74 /	29.86s		17.41s	N
	4	6.69	0.168	0.11	1.26s	19.79s		13.07s	N
	5	6.99	0.1	0.05	0.59/	22.09s		21.73s	N
MLALI	1	6.82	0.11	0.12	1.49s	8.59/		10.24s	N and P
	2	7.6	0.077	0.06	0.62/	8.25/		33.01s	N and P
	3	6.48	0.098	0.04	0.65 /	8.59/		20.65s	N and P
	4	7.22	0.151	0.02	0.30/	11.11s		21.31s	N
	5	7.7	0.124	0.12	1.60s	8.64/		19.46s	N and P
	6	7.63	0.211	0.04	0.63 /	9.19/		14.43s	N and P
IDUO	1	6.27	0.182	0.01	0.19		4.4	6.50/	N and S
	2	6.72	0.07	0.02	0.38/		5.09/	8.45/	N and P
	3	6.28	0.312	0.09	0.93 /		4.24/	4.26/	N, P and S
	4	5.56	0.125	0.07	0.89 /		0.90/	8.68s	N
	5	5.83	0.065	0.03	0.48/		3.28/	14.72s	N
	6	6.38	0.138	0.07	0.86 /		4.72/	9.30s	N

Key: *l = low, s= sufficient, ext. P = extractable Phosphorus, TN = total Nitrogen. Categorization is based on Landon [24]*

3.2 Soil pH, EC, Total Nitrogen, Organic Carbon, Extractable Phosphorus and Extractable Sulphur

Results of soil pH, total nitrogen, organic carbon, phosphorus, and sulphur of the studied soils were as presented in Table 3. The pH of the study soils ranged from 3.52 (extremely acidic) to 7.7 (moderately alkaline). Soil reaction (pH) is an indication of the acidity or alkalinity of the soil. The effect of soil pH is great on the solubility of micronutrients and the availability of macronutrients in soils [6]. The soils at Ihanda village had extremely acidic pH (3.52-5.36), the trend was such that Nghumbi<Mlali<Iduo<Ihanda, where Nghumbi soils are less acidic as compared to those of Ihanda.

The EC of soils ranged from 0.038 to 0.312 dS m^{-1}). The soils are said to be saline if the EC is greater than 4 dS m^{-1} and pH less than 8.5. In contrast, the soils with EC less than 4 dS m^{-1} and pH greater than 8.5 are referred to as sodic soils [58]. These results show that all soils in the study area are free from salts. This depicts that the soils in the study area are favourable for production of various crops as salts affect normal crop growth. Salinity is one of the limiting factors of crop production, especially in arid and semi-arid regions [25]. Soil salinization is acute in arid and semi-arid areas with shallow groundwater as well as irrigation water of poor quality [58].

The total N ranged from 0.01 to 0.15% (Table 3) which is rated as very low to low [50]. [8] Reported very low N content (0.056 % N) in soils of some areas in the Dodoma region. Furthermore, studies on soil fertility assessment conducted in the Southern highland of Tanzania showed that 77% of the studied soils had very low to low N content [22]. N deficiency in most soils is due to continuous removal from the soils through microbial denitrification, leaching, chemical volatilization, soil erosion and removal of N-containing crops [10]. The N reserves in most agricultural soils including those in the Kongwa district must therefore be replenished to optimize maize and other crop production. These provide evidence that N is a limiting nutrient in many soils of the study area. Therefore, the use of nitrogen fertilizers in these soils is necessary to improve crop yields.

Soil organic carbon ranged from very low (0.19%) to medium (1.60%) based on the categorization adopted from [4]. These findings are similar to those from a study done by Budotela [8] in selected grape-producing areas of the Dodoma region. Organic carbon plays a vital role in storage of the nutrients such as nitrogen, phosphorus and sulphur. Also, organic matter which is a derivative of OC is important in supplying plant nutrients, enhancing cation exchange capacity, improving soil aggregation and water retention, and supporting soil microbiological activities such as mycorrhizae fungi (Arbuscular mycorrhizae) and plant roots [48]. Low levels of N and OC in soils of the study area could be attributed to the farming practices adopted by the farmers including slash and burn and removal of crop residues during land preparation leading to a decrease in the biomass and overall organic matter content.

The available phosphorus in the study soils ranged from 0.14 to 53.51 mg kg^{-1} tested by the Olsen method and from 0.9 to 12 mg kg^{-1} in soils tested by the Bray-1 method. The critical values for P tested by Bray-1 and Olsen methods are 20 and 10 mg kg^{-1} respectively [24]. These results showed a low status of available phosphorus in 42% of the tested fields. Generally, a low content of P was recorded in soils with low pH. Phosphorus is directly affected by pH and not readily available in soils but P availability is better in slightly acid soils with pH ranging from 5.8 to 7.0 [24]. When the soil pH is less than 4.5, phosphates (e.g., $H_2PO_4^{2-}$ or HPO_4^{2-}) often combine with iron (Fe) and aluminium (Al) ions to form complex compounds ($Fe(H_2PO_4)_3$ or $Al(H_2PO_4)_3$), which fix P to unavailable forms for plant uptake [24]. At higher pH values, exceeding 7.5, phosphate ions exist as PO_4^{3-} and are easily precipitated by calcium (Ca) to form less soluble compounds and are likely to be unavailable to plants [24].

Extractable S (SO_4^-S) of the soils ranged from 3.43 to 33.01 (mg kg^{-1}). Sulphur levels of 8 mg kg^{-1} are critical, below that response of most tropical crops to S is expected [24]. The results of the present study indicated that 16.7% of the soils had inadequate extractable S. Kalala et al *[20]* also reported that 17 (89.5%) among 19 soil samples taken from the Kilombero district had low levels of S. Low levels of S are not only found in Tanzania but also other African countries. For instance, the studies conducted in Ethiopia reported that S deficiencies are becoming a major problem of soil fertility in tropical soils for crop production (Itanna, 2005). This low level of S is due to nutrient depletion without replenishment. Fertilization recommendations should include the optimum level of S for crop production.

3.3 Exchangeable Potassium, Calcium, Magnesium and Sodium

Results of exchangeable potassium, calcium, magnesium, and sodium in the studied soils are presented in Table 4. Exchangeable potassium in the studied soils ranged from 0.13 to 0.42 $cmol_{(+)}$ kg^{-1} which are rated as very low to medium [24]. According to Landon (1991), application of K fertilizer is likely when the exchangeable K in loamy soils is less than 0.25 $cmol_{(+)}$ kg^{-1}. The overall results indicated that 45.8% of the studied soils in the study have inadequate exchangeable K. Low exchangeable K in these soils may be caused by primarily the intensity of weathering and the nature of the parent material from which they were developed. Msanya et al. [37] reported that the main parent material for soils in Dodoma region is granite which has only 3-5% of potassium oxide. Another reason may be due to continuous cultivation for several seasons without replenishing of K nutrient using fertilizer materials rich in K [2]. Therefore, these soils require the application of K-containing fertilizers.

Exchangeable Mg in the studied soils ranged from 0.29 to 4.04 $cmol_{(+)}$ kg^{-1} which was rated as very low to very high concerning 0.20$cmol_{(+)}$ kg^{-1} level considered as critical concentration [24]. Results depicted that 29% of the selected fields in the study area were inadequate in exchangeable Mg. Furthermore, exchangeable Ca in the study soils ranged from 1.06 to 10.04 $cmol_{(+)}$ kg^{-} which has been rated as low to very high based on the ratings compiled by Landon [24]. About 25% of the selected fields in the study area were inadequate in exchangeable Ca. Low Ca content in soils could be due to the low pH values since soils with pH 6.0 or lower are likely to be deficient in Ca [12]. Exchangeable Na ranged from 0.12 to 0.28 $cmol_{(+)}$ kg^{-1}, the range is between very low to low. This means the soils are not affected by salts hence suitable for a variety of crops. These results for cations are concurrent with what was reported by Mowo, [35] who found medium levels of Ca, K, Mg and Na in Kongwa soils. Results also do not divert significantly from those reported by Msanyaet al, [37] from the study conducted in Dodoma district, central Tanzania.

Table 4. Concentrations of exchangeable bases in the studied soils of Kongwa

Village	Field No.	Potassium	Calcium	Magnesium	Sodium	Limiting nutrients
		($cmol_{(+)}$ kg^{-1})				
IHANDA	1	0.15/	1.64/	0.59/	0.14/	K, Ca and Mg
	2	0.29s	1.86/	0.82s	0.17l	Ca
	3	0.14/	2.13s	0.86s	0.12/	K
	4	0.22s	1.579/	0.726s	0.12/	Ca
	5	0.15/	1.45/	0.51/	0.12/	K, Ca and Mg
	6	0.11/	1.06/	0.29/	0.14l	K, Ca and Mg
NGHUMBI	1	0.25s	9.14s	3.41s	0.17/	
	2	0.29s	8.76s	3.40s	0.21/	
	3	0.33s	5.21s	2.38s	0.16/	
	4	0.32s	10.04s	4.06s	0.23/	
	5	0.21s	6.92s	3.05s	0.16/	
MLALI	1	0.14/	2.36s	0.77s	0.12/	K
	2	0.18/	3.68s	1.35s	0.16/	K
	3	0.24s	2.47s	1.16s	0.28l	
	4	0.42s	7.55s	2.42s	0.14l	
	5	0.16/	5.29s	1.23s	0.12/	K
	6	0.16/	5.43s	1.55s	0.14/	K
IDUO	1	0.31s	3.06s	0.40/	0.12/	Mg
	2	0.14/	2.00s	0.41/	0.12/	K and Mg
	3	0.32s	3.46s	1.45s	0.16/	
	4	0.17/	1.31/	0.45/	0.12/	K , Ca and Mg
	5	0.13/	2.05s	0.58/	0.14/	K and Mg
	6	0.23s	3.60s	1.31s	0.12/	

Key: S= sufficient, l = low

Table 5. Nutrient balance levels, base saturation and ratings of the studied soils in Kongwa district

Village	Field No.	CEC	Nutrient Balance						
		(cmol$_{(+)}$ kg^{-1})	Ca:Mg	Mg:K	TEB	BS	Ca:TEB	%K: TEB	ESP
IHANDA	1	3.54	2.83*f*	3.58*f*	2.52	67.99	0.65*uf*	6.00*f*	6.23
	2	4.17	2.56f	3.87f	3.15	73.07	0.59uf	1.00uf	6.38
	3	4.27	2.58*f*	7.29uf	3.25	74.17	0.66*uf*	4.00f	4.26
	4	3.67	2.23*f*	3.63f	2.65	72.04	0.59*uf*	9.00f	4.60
	5	3.24	3.11*f*	3.50*f*	2.22	67.41	0.63*uf*	7.00f	5.82
	6	2.62	3.75*f*	2.46*f*	1.60	60.93	0.67*uf*	7.00f	8.54
NGHUMBI	1	13.99	2.70*f*	14.22*uf*	12.97	92.43	0.70*uf*	2.00f	1.27
	2	13.67	2.62*f*	13.93*uf*	12.65	91.31	0.69*uf*	2.00f	1.81
	3	9.09	2.21*f*	8.23*uf*	8.07	87.75	0.65*uf*	4.00f	2.07
	4	15.67	2.46*f*	14.81*uf*	14.65	93.34	0.68*uf*	2.00f	1.58
	5	11.36	2.26*f*	13.83*uf*	10.34	90.14	0.67*uf*	2.00f	1.60
	6	10.48	2.03*f*	37.41*uf*	9.46	89.46	0.57*uf*	2.00f	1.76
MLALI	1	4.40	3.12*f*	5.60*uf*	3.38	76.54	0.69*uf*	4.00f	3.63
	2	6.39	2.73*f*	10.22*uf*	5.37	83.83	0.68*uf*	3.00f	2.83
	3	4.76	2.07*f*	4.83*f*	3.78	76.60	0.65*uf*	5.00f	5.90
	4	10.16	3.15*f*	9.34*uf*	10.53	91.14	0.72*uf*	4.00f	1.32
	5	9.30	4.09*f*	8.50*uf*	6.80	85.20	0.75*uf*	3.00f	2.10
	6	8.10	3.31*f*	9.07*uf*	7.29	85.95	0.73*uf*	3.00f	2.14
IDUO	1	4.22	10.14*uf*	2.98*f*	3.88	75.55	0.76*uf*	7.00f	4.02
	2	4.53	5.80*uf*	3.21*f*	2.68	71.80	0.74*uf*	6.00f	4.68
	3	5.00	2.36*f*	7.04*uf*	5.37	83.65	0.64*uf*	6.00f	2.88
	4	3.51	3.04*f*	3.11*f*	2.05	66.27	0.64*uf*	8.00f	6.09
	5	3.71	3.54*f*	4.75*f*	2.90	73.43	0.70*uf*	5.00f	4.85
	6	5.95	2.75*f*	6.94*uf*	5.26	83.68	0.68*uf*	0.04	2.31

Key: CEC = cation exchange capacity, Chemical property: Ca=calcium, Mg=magnesium, K=potassium, TEB=total exchangeable bases, f=favourable, uf=unfavourable. Based on Landon (1991).

3.4 Cation Exchange Capacity, Base Saturation, and Nutrient Balances

The cation exchange capacity (CEC), base saturation (BS), and nutrient balances of the studied soils are presented in Table 5. The CEC ranged from very low (2.62 cmol$_{(+)}$ kg^{-1}) to medium (15.67 cmol$_{(+)}$ kg^{-1}). The low CEC in soils of some fields in the study area could be due to low organic matter content [32], and the dominant clay type (Rhoades, 1982). The soils consist of mainly silica (SiO_2) which is a product of weathering from granite rocks [37]. Generally, soils high in clay are characterized by high CEC but the type of clay can substantially affect the CEC [17]. Most soils (about 74%) in this study had low clay content as point in textural classification above and hence low CEC.

The base saturation of the studied soils was high and ranged from 66.27% to 93.34%. According to FAO [13], BS greater than 50% is favourable for crop production. Therefore, most of the soils in the study area are preferably suitable for crop production.

All the fields had favourable soils with Ca: Mg ratio ranging from 2.03 to 4.09 except two farms, which had 5.80 and 10.14 while 62% of the fields had unfavourable soils with Mg: K of >4. The ratios of Ca: Mg ranging from 2 to 4 and those of Mg: K ranging from 1 to 4 are considered favourable for most tropical crops [38].

The nutrient ratios in soils are the drivers of availability of nutrients for plant uptake. This depends not only upon levels of nutrients but also on the nutrient ratios [41]. Nutrient imbalances influence nutrient uptake by inducing deficiencies of nutrients, which may be present adequately in the soil [41]. It is, therefore, important to consider the individual nutrient ratios (i.e., Ca: Mg and Mg: K), which are the indicators of nutrient uptake [18].

Table 6. Concentrations of four micronutrients in the studied soils of Kongwa District-Dodoma Tanzania

Village	Field No.	Cu (mg kg^{-1})	Zn	Fe	Mn	Limiting nutrients
IHANDA	1	0.74s	0.41*l*	30.62s	42.36s	Zn
	2	1.00s	1.84s	137.01s	46.48s	
	3	0.54s	0.94*l*	31.23s	43.82s	Zn
	4	1.57s	0.73*l*	43.97s	32.10s	Zn
	5	1.17s	0.96*l*	84.42s	34.02s	Zn
	6	0.84s	0.81*l*	71.91s	16.55s	Zn
NGHUMBI	1	1.82s	1.98s	15.61s	50.69s	
	2	2.39s	3.74s	43.73s	34.82s	
	3	2.57s	1.91s	20.48s	60.06s	
	4	4.57s	1.78s	61.27s	105.69s	
	5	2.86s	3.86s	39.11s	73.87s	
	6	2.40s	0.57*l*	37.49s	54.71s	Zn
MLALI	1	1.03s	0.99*l*	25.10s	34.91s	Zn
	2	1.29s	1.23s	18.13s	43.48s	
	3	2.15s	0.94*l*	36.86s	77.75s	Zn
	4	1.43s	0.53*l*	17.53s	55.01s	Zn
	5	1.20s	0.82*l*	15.78s	39.59s	Zn
	6	1.37s	0.56*l*	19.66s	43.87s	Zn
IDUO	1	1.18s	4.23s	20.33s	53.71s	
	2	1.07s	3.15s	27.06s	57.97s	
	3	4.86s	0.89*l*	55.28s	147.18s	Zn
	4	2.29s	0.40*l*	48.88s	66.82s	Zn
	5	2.14s	4.42s	46.04s	61.33s	
	6	3.98s	0.57*l*	44.67s	118.16s	Zn

Key: *Cu = copper, Zn= zinc, Fe = iron, Mn= manganese, l = low, s= sufficient*

3.5 Selected Metallic Micronutrients in the Study Soils of Kongwa

The concentrations of metallic micronutrients (Zn, Cu, Fe, and Mn) in the studied soils are presented in Table 6. Extractable Zn ranged from 0.41 mg kg^{-1} to 4.86 mg kg^{-1}.

Iron (Fe), Zinc (Zn), copper (Cu) and Manganese (Mn) are some of the essential metallic micronutrients that participate in various reactions in plant cells or contribute to protein structure. According to Dai et al. (2019), responses of crops to Zn application are obtained when soil Zn is 0.6 to 1.0 mg kg^{-1}. However, a critical Zn limit of 1.0 mg kg^{-1} is considered desirable for a range of crops (Landon, 1991). The soils from fourteen among 24 fields selected for this study were inadequate in extractable Zn after being compared with the critical level stated above. Low Zn contents in most of these soils is probably due to high content of free Fe, Al, and Mn ions, which cause adsorption of Zn to non-exchangeable form on their hydrated oxides surface [8,22]) reported that, iron (Fe) concentration of 4 mg kg^{1-} of soil interacts antagonistically resulting into decreased availability of Zn. Furthermore, Zn solubility decreases 100 folds for each unit increase in soil pH. This is due to the greater adsorptive capacity of the soil solid surfaces resulted from increased pH-dependent negative charges, formation of hydrolysed Zn and chemisorptions on calcite [1]. Soil pH controls the availability, solubility and mobility of trace elements including Zn, this determines their translocation in plant [41]. At low pH (3.5 to 4.8), Zn and other trace elements are usually soluble due to less desorption. At intermediate pH (5.0 to 6.2) the trend of Zn element adsorption increases to almost complete adsorption within a narrow pH range known as pH adsorption edge [41]. Brad found that at pH 5.3 the adsorption of Zn was 53% while 50% was sorbed onto humic acid in pH between 4.8 to 4.9 [41].

Extractable Fe ranged from 15.61 to 137.01 mg kg^{-11}. [52] reported that the critical level of Fe for some crops ranged from 2.5 to 5.0 mg kg^{-1}. Based on this critical range, all soils in the present study are adequate in Fe for crop production. Extractable Cu ranged from 0.54 to 4.86 mg kg^{-1}. According to [3], acceptable critical level of Cu ranges from 0.3 to 0.6 mg kg^{-1}. Therefore, the soils of the present study are adequate in Cu for crop production. Extractable Mn ranged from 16.55 to 147.18 mg kg^{-1}. The acceptable critical range of Mn for most crops range from 2.0 to 5 mg kg^{-1} [3], suggesting that the studied soils are not limited by extractable Mn for crop production.

3.6 Limiting Nutrients and Soil Fertility Groups

Data for limiting nutrients and their frequencies of occurrence are presented on Table 7.

Results indicated that N, P, K, Mg, Ca and Zn were generally the limiting nutrients of which N was limiting in all selected fields followed by K, Zn and P. Sulphur was only limiting in four (4) fields in the study soils (Table 7).

Data in Table 8 show that 12 soil fertility groups were identified and none of them is very extensive over the study area. For example, group 1 which is deficient in N alone occurs in 4 out of 24 fields which are equivalent to 16.7% of the studied fields. The remaining eleven soil fertility groups are deficient in two or more nutrients but their frequencies of occurrences ranges from three fields to one field. In general, the results show that there are wide variations in soil fertility of the study soils and hence there is no possibility of making a blanket fertilizer recommendation for all the fields.

Each soil fertility group needs its own fertilizer recommendation to optimize crop productivity. While only N is needed in soil fertility group 1, soil fertility group 2 needs N and K while soil fertility group 3 needs N, P, K and Zn. This approach will lead to site/field specific fertilizer recommendations and deployment of specific soil fertility management strategies based on limiting nutrients [20]. The rate of a nutrient to apply will come from fertilizer response experiments where the rates of a nutrient associated with optimum yields will be selected. For nitrogen and P, the rates of 60kg ha^{-1} and 40 kg ha^{-1} may be recommended on the basis of a study [35].

Table 7. Frequencies of occurrence of each limiting nutrients in 24 fields in selected villages in Kongwa district

Limiting nutrient	No. of fields it occurs	Percentage (%)
Nitrogen (N)	24	100
Phosphorus (P)	8	33
Potassium (K)	12	45.8
Magnesium (Mg)	5	21.0
Calcium (Ca)	6	25.0
Sulphur (S)	4	16.7
Zinc (Zn)	14	58.3

Table 8. Soil fertility groups and frequencies of their occurrence based on the limiting nutrients in 24 farmers' fields in Kongwa District

Soil fertility group	Limiting nutrient(s)	Frequency of occurrence (No. in %)
Group 1	N	4 (16.7%)
Group 2	N and K	3(12.5%)
Group 3	N, P, K, and Zn	3(12.5%)
Group4	N, P, Ca, Mg, K, and Zn	2(8.3%)
Group 5	N and Zn	2(8.3%)
Group 6	N, Ca, and Zn	1(4.2%)
Group 7	N, K, Mg, Ca, S, and Zn	1(4.2%)
Group 8	N and Ca	1(4.2%)
Group 9	N, P, Mg, Ca, Zn, and S	1(4.2%)
Group 10	N, K, S, and Zn	1(4.2%)
Group 11	N, P, and Mg	1(4.2%)
Group12	N, P, and Zn	1(4.2%)

3.7 Discussion

The results revealed significant variations in soil properties among the sampled fields. The predominant soil textures were sandy clay loam (48%) and sandy loam (26%), with the remaining fields classified as clay or loamy sand. Soil texture is an essential parameter that determines the composition of soil particles, which include sand, silt, and clay. The predominant soil textures in the sampled fields were sandy clay loam (48%) and sandy loam (26%) [10]. These textures play a crucial role in various aspects of soil health, such as water retention, aeration, and nutrient availability. Sandy soils have larger particles and better drainage, while clayey soils have smaller particles and retain more water [10]). This information is vital for understanding the fertility and productivity of the sampled fields. The pH of the soils ranged from extremely acidic (pH 3.52) to moderately alkaline (pH 7.7). Soil pH is a critical factor as it influences the availability of essential nutrients and the activity of soil microorganisms [41]. Acidic soils can lead to the leaching of essential nutrients, such as calcium, magnesium, and potassium, while alkaline soils can result in the fixation of phosphorus, making it unavailable to plants [4]. Knowing the pH of the soil helps in identifying the need for amendments, such as liming for acidic soils or adding organic matter for alkaline soils, to improve soil fertility and crop productivity. Organic carbon content varied from very low to medium (0.19-1.60%), and total nitrogen levels were generally very low to low (0.01-0.15%). Organic carbon is a crucial component of soil health, as it supports the activity of soil microorganisms and helps in the formation of humus. Higher organic carbon content indicates better soil quality and a more stable soil structure. Additionally, organic carbon content affects the storage and release of nutrients, making it an essential parameter to consider when assessing soil fertility and crop productivity [5]. Nitrogen is a vital macronutrient for plant growth, and its availability in the soil is critical for crop production. Low nitrogen levels can limit plant growth and lead to reduced crop yields [10]. Understanding the nitrogen levels in the sampled fields can help in determining the need for nitrogen fertilization and the potential risks of nutrient leaching.

Several nutrient deficiencies were identified in the soils. Phosphorus deficiency was observed in 42% of the soils, while 16.7% showed inadequate sulfur levels. Phosphorus is an essential nutrient for plant growth and development, playing a vital role in plant metabolism, energy transfer, and nucleic acid synthesis. Adequate phosphorus levels in the soil are crucial for optimal crop yield and quality. Sulfur is an essential nutrient for plant growth and is a component of several important plant proteins, vitamins, and enzymes. A deficiency in sulfur can lead to reduced crop growth, yield, and quality [16]. Additionally, 45.8% of the soils exhibited insufficient levels of exchangeable potassium, and exchangeable magnesium levels ranged from very low to high (0.29-4.06 cmol(+) kg-1). Potassium is an essential nutrient for plants, playing a key role in photosynthesis, enzyme activation, and stress tolerance. Adequate potassium levels are crucial for maintaining plant health and productivity [16]. Exchangeable calcium showed a range from low to very high (1.06 to 10.04 cmol(+) kg-1), maintaining a favorable base saturation for crop production. Both of these elements are essential for maintaining soil fertility and plant growth. Magnesium is a component of chlorophyll, the green pigment responsible for photosynthesis, while calcium plays a crucial role in cell wall formation and nutrient uptake.

The cation exchange capacity (CEC) of the soils varied from very low (2.62 cmol(+) kg-1) to medium (18.9 cmol(+) kg-1). CEC is an important soil property that measures the soil's ability to hold and exchange cations, which are essential for plant nutrition. A higher CEC indicates better nutrient retention and availability for plants. Extractable micronutrients, including copper, iron, and manganese, were generally found to be adequate, except for zinc, which was inadequate in 58% of the soils. Extractable micronutrients, including copper, iron, and manganese, were generally found to be adequate, except for zinc, which was inadequate in 58% of the soils. Micronutrients, such as zinc, copper, iron, and manganese, are essential for plant growth and development, playing various roles in enzyme activation, photosynthesis, and stress tolerance. Adequate levels of these micronutrients are crucial for maintaining plant health and productivity [8].

Overall, the categorization of nutrient status indicated poor fertility levels in the studied soils, particularly regarding nitrogen, phosphorus, potassium, zinc, magnesium, and calcium. The conclusion drawn from the results suggests that external nutrient inputs and proper soil management practices are essential to optimize crop production in the Kongwa District. This information provides valuable insights for farmers, agronomists, and policymakers, guiding them toward effective soil fertility management strategies for sustainable maize production in the region.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The results of the study area show deficient levels of N, P, K, S, Ca, Mg and Zn. However, there were large variations in nutrient deficiencies in different fields. This led into grouping of soils into twelve soil fertility groups. However, application of nutrients should be made based on each soil fertility group identified. In conclusion, the assessment of soil fertility status in selected fields under maize production in Kongwa District, Dodoma Region, Tanzania has provided a clear understanding of the current state of soil health and the challenges faced by farmers in the area. By implementing sustainable agricultural practices, regular soil testing, and providing education and extension services, it is possible to improve soil fertility and enhance maize productivity in the region, thereby contributing to food security and economic development.

4.2 Recommendations

Based on the findings, several recommendations can be made to improve soil fertility and enhance maize production in the Kongwa District. Firstly, it is crucial to implement sustainable agricultural practices, such as crop rotation, cover cropping, and the use of organic amendments, to maintain and enhance soil fertility. Furthermore, the adoption of conservation agriculture practices, including minimal soil disturbance, can help preserve soil structure and improve its overall fertility.

Secondly, soil testing should be conducted regularly to monitor nutrient levels and identify any deficiencies that may need to be addressed through the application of fertilizers or other soil amendments. This will enable farmers to make informed decisions about their soil management practices and ensure that their crops receive the necessary nutrients for optimal growth and yield.

Thirdly, extension services and education programs should be provided to farmers to raise awareness about the importance of soil fertility management and the benefits of adopting sustainable agricultural practices. This will empower farmers to make informed decisions about their farming practices and contribute to the long-term sustainability of the region's agricultural systems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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