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Assessment of Soil Fertility of Morogoro District, and Response of Maize (*Zea mays*) to Applied Nitrogen, Phosphorus and Sulphur

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Authors' contributions

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

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ABSTRACT

Information on soil fertility is very important on application of fertilizers as plant nutrients supplement to correct Nitrogen, phosphorus and Sulphur deficiencies. The study objective was to evaluate the current fertility status of soils of Morogoro District and the response of maize to applied Nitrogen, Phosphorus and sulphur. Two field experiments were carried out in a season 2015/2016. Eighteen maize growing areas were selected, top soils, composite samples from a depth of 0-20 cm was collected and analyzed for physical and chemical properties as per standard procedures in the laboratory. Soil analysis laboratory results used as a means for soil fertility rating. Two of those sites classified as Ultisols (Kiziwa), and Inceptisols (Fulwe) with phosphorus (P), nitrogen (N) and sulphur (S) variability were used for field experiments. Treatments for field experiment were varied fertilizer levels, namely 0, 50, 100 kg N ha^{-1}, 0, 10, 20 kg Pha^{-1} and 0, 10, 20 kg S ha^{-1}. Absolute control treatment was included in both experimental site and the experiments was arranged in a completely randomized block design with three replicates at both sites. Results showed that studied soils had low soil fertility with slightly acidic to neutral pH in

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water (6.6-7.5), Low organic carbon (0.7-1.3%), low to very low total N (<0.01) and low extractable S (<3 mg/kg). 28% of studied soils had very high concentaration of P, low to very low CEC, very high exchangeable Ca^{2+}, Mg^{2+} very low Na^{+} and adequate Concentration of K with micronutrients not limiting. Grain yield was significantly increased with application of N, P and S at *(P=.05)*. Therefore a tentative nutrient combination of 50-100 kg N ha^{-1}, 10-20 kg P ha^{-1}, and 10-20 kg S ha^{-1} may be the best strategy for improving maize yields in Morogoro District while monitoring P Concentration with time.

Keywords: Soil fertility evaluation; fertilizer levels; yield response.

1. INTRODUCTION

Maize is a cereal crop consumed as a staple food by over 80% of Tanzanians [1]. According to [2] the national average per capita consumption is 113 kg per year; and the national average maize yield is 1.69 t ha^{-1} while the potential is 4.0 t ha^{-1}. Maize production trend in Tanzania is fluctuating. It was reported to be 3 302 000, 3 555 000 and 3 324 000 t in 2007, 2008 and 2009 respectively [3]. In 2008/09 national food production for maize was 3 424 984 t while the requirement was 4 131 782 t resulting into a deficit of 706 797 t. This is because soils of the cultivated fields are highly weathered [4], and are subjected to intensive and continuous cultivation with low levels or without fertilizer application [1,4,6]. Nickson, [5] reported low total N (< 0.1) and low P (< 5 mg kg^{-1}) in some villages (Mkambarani, Changa, Ngerengere, Sinyaulime and Maseyu) of Morogoro District. Similarly zinc (Zn) and boron (B) have been reported to be deficient in 38% of soils from Kilombero and Wami valleys, Morogoro region [6]. Additionally [7] reported low total N (0.09 to 0.1) and 40% of the Morogoro district having low, P < 6.50 mg kg^{-1} soil which implies about 40% of the region should be included in the N and P fertilizer regime for optimum maize yield. Few maize farmers use inorganic fertilizers and for those using fertilizers, nitrogen is the common nutrient applied. About four percent of maize (Zea mays) producers in Morogoro District [1] apply fertilizers containing nutrients like phosphorus (P), Nitrogen (N) and sulphur (S), as a result concentration of nutrients are gradually declining in soils. Sulphur is also lost from soils through leaching, burning and crop uptake. Apart from 1 kg S and 40 g Zn lost per hectare through producing 1t grain of the high-yielding maize variety [6], other nutrients like 22 kg N, 3.1 kg P, 28 kg K are also exported from the soil. A recent study [7] supports the hypothesis that S and Zn are low and emerging as limiting factors for maize production in soils of Morogoro. Similarly, [5] soil analysis results from maize-producing areas in Morogoro district had low concentration of S and Zn, respectively. A recent researcher [8] found all (100%) of the twenty soil samples sampled in Morogoro maize production areas were N deficient while 29% were deficient in P. This suggests that application of S and P and N fertilizers is indispensable to optimize maize yields.

The only fertilizer recommendations existing in Morogoro region for maize production is that of 1993 basically for N and P. As per [8], fertilizer recommendation for maize production is 40 kg N ha^{-1} and 20 kg P ha^{-1} for Dakawa, Ilonga and Gairo. It can be concluded that, despite of the magnitude of fertilizer rates which adds the deficit nutrients in the soil, there is neither current recommendation for N, P and S. Therefore the objectives of this study were (i) To determine the fertility status of soils in selected sites of Morogoro District (ii) To determine the response of maize to application of selected limiting nutrients (N, P and S).

2. METHODOLOGY

Two field experiments were set to study the response of maize to N, P and S by applying different concentration of Nitrogen, phosphorus and sulphur in a season 2015/2016. The experimental sites were located at Kiziwa (060 46' 49.6" E / 0370 51' 21.6" S) and Fulwe (060 46' 06.9" E/ 0370 52' 31" S) in Morogoro District. Soils of Kiziwa and Fulwe are classified as Ultisols and Inceptisols respectively [4] and maize (*Zea mays L*) used as a test crop. 18 villages famous in maize production were surveyed and soil samples were collected at a depth of 0 - 20 cm for laboratory analysis. The experimental areas receive an annual rainfall ranging between 1200 and 1500 mm with temperature ranges between 26 to 32°C. After analysis two sites with varied concentration of Nitrogen, phosphorus and sulphur were selected and used for the field experiment. Two experiments were set at two different maize growing area, both evaluating the performance of different rates of N, P and S. Treatments for the field experiment were Nitrogen at a rate of 0, 50 100 kg ha^{-1}, phosphorus 0, 10, 20 kg ha^{-1} and 0, 10 and 20 kg ha^{-1} both experiment had an absolute control plot with no any nutrient applied. The experimental units of 5 m × 5 m were arranged in a completely randomized block design with three replicates at both field sites (Kiziwa and Fulwe). Other essential nutrients (i.e. Mg, Ca and Zn) were applied to avoid untargeted nutrients to limit the response of maize to P, K and S. Nitrogen was applied as Urea, K as Muriate of potash (60% K_2O), Di-ammonium phosphate as a source of N and P, Ammonium Sulphate (21% N) as a source of S (24%) and part of N, Zinc sulphate (34%) and Zinc chloride as sources of Zn. All nutrients were applied at planting except 60% N and S which was applied at 21 days after planting.

Three to four maize seeds (TMV1) were planted at 30 cm × 60 cm. At 12 days after planting the seedlings were thinned to two plants per hill. All treatments were top-dressed with N and S at 21 days after planting. All other agronomy practices for managing a maize field were observed. At maturity the crop was harvested from a plot of 3 m × 3 m, leaving the first two guard row surrounding the plot. Three rows with two plants per hole were harvested. Maize cobs were dried, shelled and dried to around 12-15% water content. Dry maize grain was weighed from each harvested plot and the results were presented in t per hector.

2.1 Laboratory Soil Test

Approximately 1 kg soil sample were collected from 18 maize growing villages and analyzed in the soil science laboratory. Particle size distribution was determined by hydrometer method after dispersing the soil particles by 5% sodium hexametaphosphate [9] and textural classes were determined by the USDA textural triangle [10]. Soil pH was measured potentiometrically in water at a ratio of 1:2.5 soil–water [11]. Basic cations (Ca, Mg, K and Na) from ammonium acetate (NH4Oac) leachate [12]. The total exchangeable bases (TEB) were calculated arithmetically as a sum of four exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+). Available Micronutrients were determined by Diethylene triamine penta acetic acid (DTPA) method and their respective concentration in the filtrate were determined by atomic absorption spectroscopy using appropriate standards [13]. Extractable sulphur was extracted by Calcium orthophosphate method [14]. The Organic carbon content of the soils was determined by chromic acid wet digestion method [15].

2.2 Data Analysis

All the data collected, concentration of nutrients in soils, grain response to N, P and S were subjected to analysis of variance using GenStat Discovery Edition 4. Means were compared by Duncan multiple range test (DMRT) at P =0.05. The coefficient of variation (CV) in percentage was recorded.

3. RESULTS AND DISCUSSION

3.1 Soil Fertility of Morogoro District

3.1.1 Particle size distribution

Particle size distribution is presented in Table 1. The average soil texture was sandy clay loam, clayey to sandy loam. [10] reported that soils with more than 65% sand and less than 18% clay frequently have low fertility status. Therefore soils of Fulwe, Changa, Kikundi, Gozo, Pangawe, Kibangire, Mkambarani, Maseyu, and Kiziwa are likely to have inadequate soil fertility. Soil texture is the composite of coarse fraction (sand) and the finer fraction (silt and clay) and any alteration in one component affects the other component therefore affecting the phyisico-chemical properties of the soils [10].

3.1.2 Chemical properties

Some soil chemical properties of the studied soils are presented in Table 2. The soil studied was generally slightly acidic to neutral (6.6 - 7.5). [13] suggested that pH of dry soils ranging from 5.5 to 6.5 is satisfactory for production of a variety of crops. This pH range favours availability of plant nutrients like N, P, K, S, Ca, Mg, Bo, Cu, Fe and Zn [13].

According to [16] the studied soils had low organic carbon contents (0.7-1.3%). Other results [11,17] indicated soils from these areas are characterised by low organic carbon concentration. It has been established that N availability for plants uptake is positively correlated with the quality and

Table 1. Particle size distribution of top soils in Morogoro District (0-20 cm)

Site	Clay (%)	Silt (%)	Sand (%)	USDA textural classes
Kingolwira	48.8	8.9	42.2	Clay
Mkambarani	20.8	8.9	70.2	Sandy clay loam
Lubungo	20.8	6.9	72.2	Sandy clay loam
Mlali	16.8	8.9	74.2	Sandy loam
Kiroka	20.8	6.9	72.2	Sandy clay loam
Mkonowa Mara	28.8	20.9	50.2	Sandy clay loam
Bigwa	24.8	10.9	64.2	Sandy clay loam
Kibangire	14.8	10.9	74.2	Sandy loam
Kiziwa 1	18.8	8.9	72.2	Sandy loam
Kiziwa 2	20.8	12.9	66.2	Sandy clay loam
Maseyu	12.8	10.9	76.2	Sandy loam
Pangawe	20.8	12.9	66.2	Sandy clay loam
Kibangire	34.8	16.9	48.2	Sandy clay loam
Gozo	16.8	10.9	72.2	Sandy loam
Kikundi 1	14.8	6.9	78.2	Sandy loam
Kikundi 2	18.8	4.9	76.2	Sandy loam
Fulwe	14.8	4.9	80.2	Sandy loam
Changa	10.8	6.9	82.2	Loamy sand

Table 2. Chemical properties of representative top soils from selected sites of Morogoro District

Location	pH_{H20}	Total N (%)	P (mg/kg)	S (mg/kg)	OC (%)	CEC (cmol (+) /kg)
Kingolwira	6.2	0.14	6.4	0.44	1.3	16
Mkambarani	6.7	0.20	5.6	0.24	0.7	20.9
Lubungo	6.9	0.14	28.9	0.3	0.7	13.3
Mlali	6.5	0.14	28.9	0.49	0.6	15.4
Kiloka	6.1	0.14	28.3	0.34	1.3	13.7
Mkonowa Mara	6.8	0.20	30.3	0.54	1.3	24.1
Bigwa	7.2	0.14	13.7	0.34	0.6	6.9
Kibangire	6.5	0.13	42.1	0.23	1.3	9.3
Kiziwa 1	6.5	0.19	9.6	0.45	1.3	10.7
Kiziwa 2	6.7	0.13	6.4	0.5	1.3	11.3
Maseyu	6.8	0.14	4.8	0.34	1.3	19.8
Pangawe	7.5	0.16	19.1	0.51	0.6	14.7
Kibangire	6.4	0.20	29.3	0.35	0.7	4.8
Gozo	7.2	0.15	9.7	0.19	1.3	13.7
Kikundi 1	6.8	0.14	8.4	0.26	1.3	14.7
Kikundi 2	6.4	0.09	5.6	0.33	1.3	14.1
Fulwe	6.5	0.15	9.2	0.31	1.3	5.9
Changa	7.1	0.10	41.4	0.23	1.3	8.2

decomposition of organic matter in soils. Therefore application of N to these soils is advised for optimum maize production in soils of Morogoro District. Generally low values of OC in the present study may be attributed to low accumulation and rapid decomposition of plant residues into the soil every season [13].

Total N concentration varied from 0.09 to 0.2%. Based on guidelines compiled by Msanya [15], of the soils tested, Mkono wa mara and Fulwe had low total N (0.15% and 0.2% respectively) while the rest had very low total N (<0.1%). According to [2], In soils, the concentration of nitrogen is closely related to the amount of soil organic matter which makes approximately 5% of soil volume. These results indicated that all the soils tested had very low to low concentration of total. Low N concentration implying inability of the soil to supply adequate N for plant growth. This means that nitrogen fertilizers have to be applied each time when maize cultivation is done and this is evident in all tested soils.

Concentration of Bray-I extractable P for soils of some sites [13] was observed to be above critical values. The high values extended from 28.9 mg/kg to 42.1 mg/kg as adequate for maize production for soils of Lubungo, Mlali, Kiroka, Changa and Kibangire. This is contrary to (38.9%) which had relatively low extractable P ranging from 4.7 mg/kg to 9.7 mg/kg suggesting inadequate P for maize production in the particular locations. This means that over 30% of the soils in Morogoro district have low concentration of P and require P application for optimum maize production. The results by [16], supports this findings, and low P results of this research is thought to be associated with continued land use and soil fertility deterioration.

Sulphur in the studied soils varied from 0.2 to 0.5 mg/kg. According to [13] soils of Morogoro District had low extractable S. Similarly low concentration of S was obtained in soils of Kibena tea Estates. Results indicates that all the soils tested in Morogoro District require application of S for optimum maize production. According to [13], S enhances P uptake by plants and calcium can cause S precipitation and therefore, reducing S availability to plant. Retaining plant residues into fields and addition of S containing fertilizes will help to manage S problem in these areas.

3.1.3 Exchangeable bases

Concentration of determined exchangeable bases (Ca, Mg, Na, and Na) in top soils of representative maize growing villages is presented in Table 3.

3.1.3.1 Calcium

Calcium concentration in tested soils ranged between 0.6 to 13.9 cmol (+) kg^{-1}) (Table 3). According to [18] soils of Kingolwira, Mkambarani, Lubungo, Kiroka, Mkono wa Mara, Bigwa and Kibangire with textural class of sandy clay loam, had Ca^{2+} values ranging from 0.6 cmol (+) kg^{-1}) to 3.1 cmol (+) kg^{-1} being rated as very low to medium, the rest had calcium values ranging from 4.8 cmol (+) kg^{-1}) to 9.4 cmol (+) kg^{-1}), loamy soils being rated high. [19] suggested that maximum maize growth occurs when Ca^{2+} saturation is about 8- 20% of the CEC. Concentration of Ca for soils of Mlali, Pangawe, Kikundi and Kiziwa was within the range, while the rest of the soils were below this range, implying possibility of Ca^{2+} deficiency to maize grown in those areas.

Table 3. Concentration of exchangeable bases on top soils from 18 sites in Morogoro District

Location	Exchangeable bases cmol(+)/kg			
	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}
Kingolwira	0.6	3.1	3.2	0.48
Mkambarani	1.1	3.8	1.9	0.13
Lubungo	1.4	2.4	1.8	0.09
Mlali	13.9	2.1	1.3	0.52
Kiroka	1.4	2.2	0.8	0.07
Mkonowa Mara	1.1	2.8	0.6	0.17
Bigwa	3.4	1.5	2.5	0.58
Kibangire	1.3	1.6	0.9	0.17
Kiziwa 1	6.1	2.1	0.9	0.09
Kiziwa 2	9.4	6.3	1.9	0.07
Maseyu	5.7	2.7	0.7	0.11
Pangawe	8.9	1.8	2.3	0.64
Kibangire	4.8	2.3	0.6	0.09
Gozo	5.3	1.3	1.1	0.09
Kikundi 1	7.8	6.3	1.5	0.11
Kikundi2	8.1	5.1	0.5	0.07
Fulwe	3.5	2.2	1.1	0.11
Changa	5.7	2.7	0.4	0.04

3.1.3.2 Potassium

Exchangeable K^{+} for the studied soils of Morogoro district varied from 0.6 to 3.1 cmol(+) kg^{-1}). According to guidelines compiled by [19], soils of Kiroka, Mkono wa Mara, Maseyu, Kikundi, Changa, Bigwa and Kibangire, with textural class of sandy loam had extractable K ranging from 0.4 - 0.9 cmol(+) kg^{-1}) which was rated as high. The rest of the tested soils had K^{+} values above the critical values. These results indicated that all the soils tested in Morogoro District had adequate concentration K. [13] suggested that K deficiency may appear when K is very low in soils and when it drops below 2% of the CEC.

3.1.3.3 Magnesium

Magnesium concentration ranged from 1.3 to 6.3 cmol(+) kg^{-1} Table 5. Agricultural soils of Morogoro district had high concentration of extractable Mg (1.3 - 6.3 cmol (+) kg^{-1}. According to [13] deficiency of magnesium may appear when exchangeable Mg drops below 3-4%, hence the studied soils had adequate Mg for maize production. Concentration of extractable Na varied from 0.07 -0.64 cmol (+) kg^{-1}. Of the soils tested, soils of Kingolwira, Mlali, Bigwa, and Pangawe had Na values from 0.4 to 0.6 cmol(+) kg^{-1}. Based on Guidelines complied by [19] Na values are rated as medium. The rest had very low to low concentration (0.1 - 0.3 cmol(+) kg^{-1}. This suggests that concentration of Na in Morogoro soils will provide conducive environment for maize production. [5] documented that when high percent of the CEC is occupied by Na, soil structure is destroyed by dispersing soil aggregates leading soils impermeable to water, the situation becomes even more serious in clay soils.

3.1.4 Concentration of extractable micronutrients

Micronutrients determined were Copper, Zinc, Manganese and Iron (Table 4). According to [13,19], the critical range of copper is 0.1 to 0.25 mg Cu /kg. Concentration of Cu found in the 18 soils were all above the critical range hence the soils tested had adequate concentration of Cu. Overall results indicate that agricultural soils of some parts of Morogoro District would supply adequate Cu for optimum growth of crops.

The critical range of Zn in soils [13,18] is 0.2 to 2.0 mg Zn /kg. Of the studied soils, soils of Fulwe, Kibangire and Maseyu had relatively low values of Zn falling on the lower limit of the critical range implying Zn deficientin the study area. However, the findings portray the rest of the soils tested have adequate concentration of Zn for optimum production of crops.

The critical range for iron is 2.5 to 5.0 mg /kg and 1.0 to 5.0 mg /kg for manganese [13,20]. It was documented by [13] that Mn is rated as high when more than 2000 mg /kg are found in soil. Therefore the concentration of Mn in the current study were to not limiting and not to toxic in the soils tested.

3.1.5 Grain yields as affected by N, P and S at Kiziwa and mikese field trials

3.1.5.1 Response of N application on maize grain yield at Kiziwa and Mikese

Grain weight per plot was significantly affected by application of N Table 6. Maize crop fertilized at the rate of 50 and 100 kg N produced maximum grain yield of 5.7 and 5.2 t at Mikese and Fulwe respectively which was statistically significantly (P = .05), from the control plot. Highest grain yield was recorded at the rate of 100 kg N at Fulwe and Kiziwa. The increase in grain yield by increase in N concentration is thought be due to increase in grain number per cob, more grains per row and cob length. The increase in grain weight at tasselling due to increase in N application is ascribed to its positive effects on plant height, stem diameter and leaf number per plant and enhanced crop growth rate and net assimilation rate which ultimately increased the grain yield [14]. Higher grain yield with nitrogen application was also reported by [20,14,21]. Following this study nitrogen rates of 50 kg N at Fulwe and 100 kg N at Kiziwa should be applied in maize production in order to optimize maize yield.

Table 4. Concentration of extractable micronutrients of representative agricultural soils in Morogoro District

Location	Micronutrients (mg/kg)			
	Cu	Zn	Mn	Fe
Kingolwira	1.21	1.17	97.4	42.2
Mkambarani	0.8	0.9	52.9	67.2
Lubungo	1.6	2.3	52.9	70.1
Mlali	0.6	2.7	40.2	78.9
Kiloka	1.8	4.4	41.8	94.4
Mkonowa Mara	0.4	3.6	106.9	122.2
Bigwa	1.3	1.1	26.7	13.3
Kibangire	1.1	2.8	48.1	78.9
Kiziwa 1	1.1	0.7	48.2	34.4
Kiziwa 2	1.3	3.7	60.8	46.7
Maseyu	0.8	0.3	32.3	77.8
Pangawe	1.1	0.7	33.9	11.1
Kibangire	1.3	0.3	40.2	31.1
Gozo	0.8	0.8	34.7	18.9
Kikundi 1	0.5	1.1	46.6	35.6
Kikundi 2	0.5	0.5	32.3	66.7
Fulwe	0.4	0.2	29.3	2.2
Changa	0.5	3.7	92.6	35.1

3.1.5.2. Response of Sulphur application on maize grain yield at Kiziwa and Mikese

Maize yield increased with Sulphur application at both experimental sites.(Table 6). Grain yield increased with S application from 2.7 and 1.4 t at Fulwe and Kiziwa control plots to maximum grain yield of 7.9 and 5.2 t in treatment plots where S was applied at 20 kg S ha^{-1} plus all other limiting nutrients. Both experimental sites had statistically significant yield increases to applied S. This increase in grain yield by the application of S is associated with requirement for disulphide bond formation between polypeptide chains. Sulphur is required for the synthesis of various metabolites example Co-enzyme A which is involved in the oxidation and synthesis of fatty acids [5]. These results are in conformity to those reported by [17].

Table 5. Initial Status of plant nutrient at the experimental sites

Particulars	Kiziwa	Fulwe	Method
%Sand	66.2	80.2	Hydrometer method
%silt	12.0	4.0	
%clay	20.8	15.8	
pH	6.7	6.5	pH Meter
N(%)	0.13	0.15	
OC(%)	1.3	9.2	Glass Electrode pH Meter
P (mg/kg)	6.4	0.3	Bray -1
S(mg/kg)	0.5	1.3	
CEC	11.3	5.9	
Ca	9.4	3.5	
Mg	6.3	2.2	
K	1.9	1.1	
Na	0.07	0.11	
Cu	1.3	0.4	
Zn	3.7	0.7	
Mn	60.8	29.3	
Fe	46.7	22	

3.1.5.3 Effects of P rates on maize grain yield in Fulwe and Kiziwa sites

The effects of P fertilizer rates on maize grain yield at Fulwe and Kiziwa sites are presented in Table 6. All fertilizer treatments produced significantly higher grain yield than the absolute control. Grain yield increased with P application up to 6.4 t at Fulwe and 5.0 t at Kiziwa. Differences in grain yield response of maize at the two sites were significant at P=.05. These results indicate that soils across the study sites were deficient in nutrients especially P (Table 6) and fertilizer application is crucial for maize production. These results are close to those reported by [7] who revealed highest grain yield when 30 kg P ha^{-1} with other plant nutrients taken into account (B, Mo, Zn, Mn and S) were applied. This affirms that nutrient balance plays a significant role in increasing crop production and its quality. For the major processes of plant development and yield formation, the presence of nutrients like N, P, K, S, Mg and Zn at balanced concentration and good crop husbandry practices is essential [14,22].

Table 6. Grain yields at treatment effect on maize yeld at Fulwe and Kiziwa

Treatment	Fulwe (t/ha)	Kiziwa (t/ha)
$N_0P_0K_0S_0ZN_0$	2.7a	1.4a
N_0P_{20} K_{50} $S_{20}ZN_{10}$	3.5abc	1.8a
N_{50} $P_{20}K_{50}S_{20}ZN_{10}$	4.2abc	3.8 bc
$N_{100}P_{20}K_{50}S_{20}ZN_{10}$	5.7cd	5.2 e
$N_{100}P_0K_{50}S_{20}ZN_{10}$	4.1abc	3.8bc
$N_{100}P_{10}K_{50}S_{20}ZN_{10}$	4.5bc	4.7cde
$N_{100}P_{20}K_{50}S_{20}ZN_{10}$	6.4de	5.0 de
$N_{100}P_{20}K_{50}S_0ZN_{10}$	3.2ab	3.9bcd
$N_{100}P_{20}K_{50}S_{10}ZN_{10}$	5.1cd	5.2e
$N_{100}P_{20}K_{50}S_{20}ZN_{10}$	7.9 e	5.2 e
CV (%)	19.8	6.6

Means bearing same letter(s)in the same column are not significantly different (P=.05) using Duncan's Multiple Range test

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusions

It was concluded that:

i. Soils of the studied areas have low to medium soil fertility, the major limiting nutrients were N, S and P while Zn was inadequate in 20% of the studied soils.
ii. From the two field experiments it was found that maize crops responded positively to application of N, P, and S. The optimum rates of N, S and P were; 50-100 kg ha^{-1}, 10-20 kg ha^{-1} and 10-20 kg ha^{-1} respectively.

4.2 Recommendations

i. Nitrogen, Sulphur should be applied for better maize yield, while monitoring the trend of phosphorus and Zinc in Morogoro soils. Further studies should be done to confirm the suggested fertilizer application rates of N, P, and S for soils of Morogoro District while monitoring the concentration of P in the soil with time.
ii. Agricultural extension staff in collaboration with researchers is advised to disseminate the knowledge to farmers on the importance of using fertilizers in the area.
iii. Evaluation of soil fertility status should be done in potential maize growing areas so as to cover a larger area in order to understand the fertility situation of the area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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