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Evaluation of selected soil fertility parameters for improvement of fertilizer recommendations in Zambia

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Abstract

The fertilizer practice among smallholder farmers in Zambia is to apply the same amount of fertilizers to crops regardless of soil type and climatic conditions. The blanket fertilizer application across soil types and agroecological regions (AERs) is not efficient. In this study we evaluate the influence of soil type and climate on selected soil fertility parameters that are used to determine fertilizer recommendations. Samples of three different soil types were obtained from AER I and IIa and analyzed for selected soil fertility parameters using standard laboratory methods. Individual parameters were subjected to a two-way ANOVA to determine any differences among soil types and across AERs using the general linear model procedure. The soil variables showed that significant differences in soil fertility status exist among soil types and across AERs at various p values. The differences associated with soil types are more pronounced in soil chemical fertility parameters ($p < 0.01$ and $p < 0.05$), while differences associated with AERs are evident in the soil physical parameters ($p < 0.01$ and $p < 0.001$). The measured values of soil fertility parameters are categorized into different classes in terms of optimality, levels of adequacy and deficiency. Results of the study suggests that the current blanket fertilizer recommendation is inadequate because it does not take into account variations in the soil fertility status across soil types and AERs. Understanding how the soil fertility characteristics and their interaction with AERs influence soil fertility status is an important guide to more efficient fertilizer recommendations.

Keywords—Soil fertility parameters; soil type; agroecological region

I. INTRODUCTION

Soil acidity, low organic matter content, plant available water and low nutrient retention capacity are soil fertility parameters that present major constraints to crop production [1], [2]. Without appropriate management, poor fertilizer application practices among others have been reported to worsen the situation in Zambia [3], [4], [5] and elsewhere [6], [7]. A general lack of knowledge and understanding of specific soil fertility parameters and their limitations in the relevant soils are at the basis of poor fertilizer application practices [8]. These soil fertility parameters vary with soil type and climate. Therefore, blanket fertilizer recommendations across soil types and AERs as practiced in Zambia are unlikely to result in efficient fertilizer use.

Acknowledging that fertilizer use is very expensive and can have undesired effects if not used appropriately, precision agriculture methods can be considered as the best option that can lead to optimal fertilizer use. Precision agriculture technology is recognized as a major contributor to farming efficiency and environmentally friendly farming practices [9]. However, blanket fertilizer recommendations do not take this into account. The concept of precision agriculture involves the assessment of in-field spatial variability of different factors such as fertility, soil type and characteristics, and water content in a field and the subsequent management of each crop production input in a more precise and site-specific manner according to the variability [10].

Although, precision agriculture is not widely applied in Zambia, the Zambia Soil Health Consortium (ZSHC) recommends using the 4R nutrient stewardship, a science-based framework that focuses on applying the right fertilizer source at the right rate, at the right time and in the right place. However, the blanket cover fertilizer recommendations pose challenges to the ZSHC recommendations, because in its formulation, soil types and inherent soil fertility aspects are not taken into account.

The standard fertilizers available in Zambia are generally formulated on the assumption of the homogeneity of soil response to fertilization. Ignoring soil variations and climatic differences may be less costly in terms of time and resources required, but often fail to yield desired results [11]. Therefore, recognizing the differences in soil types and their intrinsic characteristics as well as the way they respond to fertilizer application would be a good step towards being able to follow the ZSHC recommendations for the right fertilizer source, right application rate, right time and right place. Consequently, having knowledge on soil types and their inherent soil fertility opens up the potential to make fertilizer recommendations based on specific soil types to optimize their use.

This study was conducted to evaluate the influence of soil type and climate on selected soil fertility parameters that are used to determine fertilizer recommendations. This was done to lay a foundation for further studies on precision agriculture. It is hypothesized that the two factors (soil type and AER) have no significant effect on soil fertility status as represented by the selected soil fertility parameters.

II. MATERIALS AND METHODS

A. *Study Area*

The study was conducted in Agro-ecological regions (AER) I and IIa in Zambia, which lie within latitude 12o and 17o S, and longitude 23o and 34o E (Figure 1). AER I includes areas of southern, eastern and western Zambia. Region IIa includes much of central Zambia, and extends into Southern, Eastern and Lusaka provinces.

AER I mostly covers valley regions lying between 300-800 m altitudes above sea level. The region is characterized by a mean annual rainfall ranging from 600 to 800 mm and has erratic rainfall distribution. Average mean daily temperatures range from 35- 40°C in the hottest month of October to 7-15°C in the coldest months of June and July. The soil type predominantly found in region I are Podzols and Leptosols. The physical characteristics of these soils, which constitute significant constraints for crop production, include: erosion, limited soil depth in hilly and escarpment areas, poor physical properties and low water holding

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capacities in sandy soils.

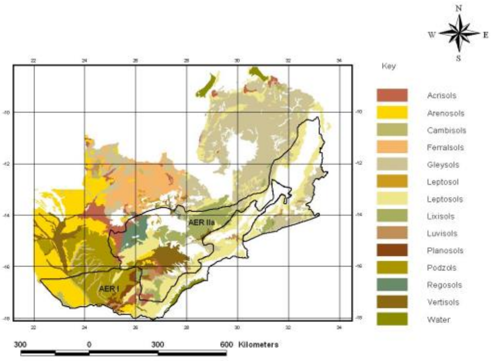


Figure 1: Map of Zambia showing AER I & IIa and soil types

Region IIa lies within medium to low altitude areas with a mean annual rainfall averaging between 750-1000 mm. Distribution of rainfall is not as erratic as in Region I, but dry spells are common. Average mean daily temperatures range from 23- 26°C in the hottest month of October to 16-20°C in the coldest months of June and July. The most dominant soils in Region IIa are Lixisols and Vertisols. Physical characteristics of the soils that affect crop production include low water holding capacity, poor physical properties that make it difficult to till especially on cracking clay soils, crusting, low water holding capacity in sandy soils, shallow rooting depth, and top soils prone to rapid deterioration and erosion.

B. *Field Method*

Four districts, namely Chibombo and Mazabuka (from AER IIa) and, Sesheke and Sinazongwe (from AER I), were selected as representative study sites (Figure 2). The four districts were selected because they form part of the sampling frame of the Rural Agricultural Livelihoods Survey (RALS) which is a nationally representative agricultural household survey implemented by the Indaba Agricultural Policy Institute (IAPRI) in collaboration with Central Statistical Office (CSO) that collects detailed data on agricultural practices including CA practices. RALS 2015 will be used to assess the impact of CA under different soil types, however, the data set does not include soil variables to allow for this, which is the gap bridged in this study.

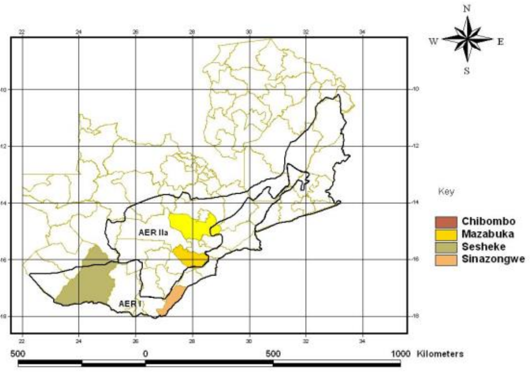


Figure 2: Map of Zambia showing sampling districts

A soil map of Zambia was used as a base map for identifying dominant soil types in the four districts after overlaying it with ward and district administrative boundary map using Arc GIS Version 10 software. For the purpose of this study the FAO taxonomy was adopted to classify soil types. The identified soil types were Leptosols and Podzols from AER I, while in region IIa had Leptosols and Lixisols (see Table 1).

Table 1: Percentage coverage of soil types for each agroecological region

AER	Total Area (ha)	%Area covered by Leptosols	%Area covered by Lixisols	%Area covered by Podzols	%Area covered by Others
I	15,171,604	34.7	0	37.6	27.7
IIa	21,739,471	27.8	15.5	0	56.7

An AER map was generated and superimposed on the soil type and district administrative boundary map to verify the location of the districts with respect to the AERs.

Representative composite soil samples were randomly collected from arable virgin land at a depth of 0 - 30 cm in RALS target districts based on dominant soil type. Virgin land was selected to be representative sites for soil sampling instead of farmers' field in order to account for the effects of various soil management levels and practices under CA fields, given different soil types. A composite sample was made of five sub-samples randomly collected within a 15-square kilometer area of the identified dominant soil type. The distance between sampling points was dependent on the occurrence of virgin land. All sampling points were georeferenced to tag their location.

C. *Laboratory Soil Analysis*

The soil samples were air dried at room temperature and then sieved through a 2-mm sieve. The technical soil fertility evaluation involved analysis of, soil reaction (pH), soil texture, organic carbon (OC), available phosphorus (AP), total nitrogen (TN), exchangeable acidity, effective cation exchange capacity (ECEC), exchangeable bases, soil water content at field capacity (FC), permanent wilting point (PWP) and soil water retention capacity.

The pH of the soils was measured in calcium chloride (0.01M CaCl) suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combination electrode [12]. The exchangeable acidity (Al3+ + H+) was determined titrimetrically according to the routine methodology adapted from [13]. The procedure involved titration of 1M KCl extract with 0.01M NaOH, using phenolphthalein as an indicator (titration from colorless to pink). Then, the concentration of Al^{3+} was obtained by back-titration of the same KCl extract with 0.01 HCl (titration from pink to colourless).

Walkley and Black method [14] as modified by Allison [15] was used to determine organic carbon and percent soil organic matter (OM) was obtained by multiplying percent soil OC by a factor of 2 following the assumptions that OM is composed of 50% carbon. The procedure involved the oxidation of the soil OM with potassium dichromate (K_2 Cr_2O7) using concentrated sulphuric acid (H_2SO_4) and the percentage OC found by titrating with IN ferrous ammonium sulphate solution.

The Kjeldahl method according to Bremner [13] using $CuSO_4$-K_2SO_4 catalyst mixture was used to determine total nitrogen. The ammonia (NH3) from the digestion was distilled with 10M Na0H into Boric acid indicator-solution and determined by titrating with 0.01M standard HCl. The available phosphorus was determined using the Bray 1 method [16] (using a mixture of 1M Ammonium Fluoride and 0.5M HCL extracting solution). The determination of available phosphorus was made by spectrophotometry using molybdenum blue.

Exchangeable bases (Ca, Mg, K and Na) were determined after extracting the soil samples by ammonium acetate (1N NH4OAc) at pH 7. Exchangeable Ca and Mg in the extracts was determined using atomic absorption spectrophotometer, while Na and K was determined by flame photometer [17].

The soil electrical conductivity (EC) was determined using a 1:5 soil – water extraction method. The soil sample was mixed with distilled water and the mixture was then placed on the reciprocating shaker for one hour. The mixture was filtered and the filtrate was collected for the measurement of EC corrected at 25oC using a standardized conductivity meter [18].

The soil texture was determined by the soil particle distribution analysis using hydrometer method [19] after dispersing the soils with sodium hexameta phosphate (NaPO3). In order to determine the available water holding capacity (AWHC), water content at FC and WP of the normal compacted soil was estimated at 33 kPa and 1500kPa soil water potential using the Soil Water Characteristics software [20] using sand and clay percentages as input parameters.

D. *Statistical analysis*

The soil physical and chemical properties were analyzed using the general linear model procedure following Analysis of Variance (ANOVA) using SPSS 20.0 (IBM SPSS, Inc., Chicago, IL, USA). Individual soil fertility parameters were subjected to a two-way ANOVA to determine if there were differences in the soil fertility variables (pH, TN, OM, AP, exchangeable bases, exchangeable acidity, ECEC, EC, texture, AWHC, FC, PWP) among soil types and between AERs. The dependent variable scores were subjected to a two-way analysis of variance across three levels of soil type (Leptosol, Lixisol, Podzol) and two levels of agro ecological region (AER I, AER IIa) (Table 1). All effects were statistically significant at the 0.05 level. Simple correlation analysis was executed following the procedure outlined by Gomez and Gomez [21] to show the magnitudes and directions of relationships between selected soil fertility parameters within and across soil types and AERs. This also helped in focusing the discussion around the most relevant fertility variables among the set of variables that were analyzed.

The data on the dependent variables were checked to ensure that they met the two-way ANOVA assumptions. Outliers in the data were assessed by inspection of box plots and removed from the data set where they were found to be influential. The normality of the data was assessed by checking their kurtosis and skewness before verifying it with the Shapiro-Wilk test ($p>0.05$). In terms of skewness and kurtosis it was assumed that the data were approximately normally distributed if they did not differ significantly from normality (z-value between -1.96 and +1.96). Where the normality of the data distribution was violated a logarithmic or inverse difference transformation was performed on the datasets before the analysis and a back transformation done during the result interpretation. The Levene's test for Equality of Variances ($p > 0.05$) was used to check for the homogeneity of variance and a post hoc multiple comparison done using least significant difference (LSD). Where equality of variances was violated ($p < 0.05$), equal variance was not assumed and the correction/procedure Games-Howell was used. Separate variances and the Welch-Satterthwaite and Brown-Forsythe test were used to test the equality of mean [22], [23]. Where the data set could not be transformed, a non-parametric procedure, Kruskal-Wallis test and Mann-Whitney test was followed to compare means. Follow-up tests were conducted to evaluate pairwise differences among the three soil types and two AER, controlling for Type I error across tests by using the Bonferroni approach [24].

III. RESULTS

A. *Influence of soil type on soil fertility parameters*

To test the hypothesis that the soil types were associated with statistically different means of selected soil fertility parameters, a two-way analysis of variance was performed. The soil variables showed that significant differences at various p-values existed in soil fertility status among different soil types. The differences among soil types are pronounced in both soil bio-chemical and physical fertility parameters (Tables 2 – 6). These differences underscore the influence of soil type on soil fertility parameters that are used in determining fertilizer recommendations. Therefore, the results of this study demonstrate that knowing the magnitudes of soil fertility parameters and understanding how they interact among themselves in a given soil is very important. Table 7 summarizes the relationships among soil fertility parameters in a correlation matrix. OM content pH, texture exhibited significant correlations among themselves and with other soil variables.

B. *Soil reaction (pH)*

An analysis of variance showed that the influence of soil type was significant, F (2, 32) = 4.39, p < 0.05 pointing to the differences in average pH values among soil types (Table 2). Figure 3 shows the bar graphs depicting pH levels per soil type. According to the classification by McPhillips (1987), the mean pH among soil types in this study can be classified as strongly acid (pH between 4.5 and 5.0).

C. *Organic Matter (OM)*

The main effect of soil type yielded an F ratio of F (2, 35) = 8.79, p < 0.05, indicating that the mean OM content as illustrated in Figure 4 was significantly different among the soil types (Table 2). Based on Landon (1991) soil organic matter classification, the OM content of all the three soils are very low (less than 2%)

Figure 3: Comparison of average soil pH by soil type and AER

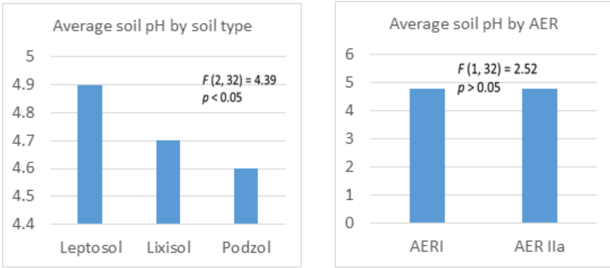


Figure 4: Comparison of average percentage soil OM by soil type and AER

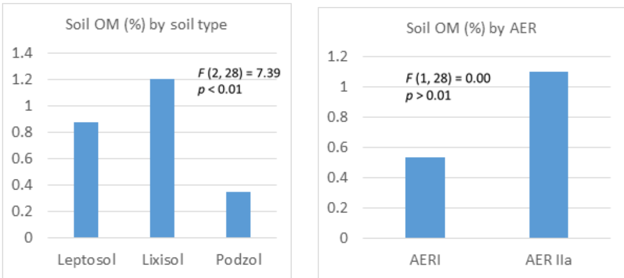


Table 2: F-statistics and means with their standard deviations of selected soil parameters by soil type and agroecological

	Soil Type				Agroecological Region		
	Leptosols	Lixisols	Podzols	$F_{soil\ type}$	AER I	AER IIa	F_{AER}
pH	4.9(0.22)[a]	4.7(0.24)[ab]	4.6(0.18)[b]	4.39*	4.8(0.24)	4.8(0.22)	2.39
OM (%)	1.03(0.32)[a]	1.55(0.55)[b]	0.41(0.29)[c]	7.39**	0.63(0.42)	1.40(0.54)	0.00
TN (%)	0.09(0.03)[a]	0.21(0.13)[b]	0.08(0.05)[c]	5.29*	0.08(0.04)	0.17(0.12)	0.01
AP (ppm)	4.19(1.86)	2.81(1.92)	3.48(1.22)	1.71	3.97(1.52)	3.01(1.94)	1.61

Means with the same superscripts letters within a row are not significantly different from each other. Single asterisk "" indicates that the difference is significant at $p < 0.05$ and a double asterisk indicates that the difference is "**" ($p < 0.01$). An F-statistic without any asterisk means the difference between means is not significant.*

Table 3: F-statistics and means with their standard deviations of Exchangeable Bases and Effective Cation Exchange Capacity by soil type and agroecological region

	Soil Type				Agroecological Region		
cmol(+)/kg soil	Leptosols	Lixisols	Podzols	$F_{soil\ type}$	AER I	AER IIa	F_{AER}
Ca	0.18(0.09)	0.13(0.08)	0.07(0.05)	2.6	0.11(0.08)	0.15(0.09)	0.35
Mg	0.09(0.05)[a]	0.06(0.04)[b]	0.01(0.05)[c]	7.23**	0.04(0.05)	0.07(0.06)	2.92
K	0.30(0.12)[a]	0.25(0.10)[a]	0.13(0.07)[b]	6.04**	0.18(0.11)	0.27(0.10)	2.44
Na	0.45(0.31)[a]	0.47(0.25)[a]	0.16(0.12)[b]	6.04**	0.32(0.33)	0.43(0.23)	2.66
Exch. Acidity	0.19(0.14)[c]	0.57(0.29)[b]	0.62(0.19)[a]	11.80***	0.45(0.29)	0.46(0.30)	0.44
ECEC	1.21(0.72)	2.50(0.38)	1.85(0.34)	0.6	2.02(0.57)	2.49(0.48)	0.03

Means with the same superscripts letters within a row are not significantly different from each other. Single asterisk "" indicates that the difference in the means is significant at $p < 0.05$ and a double asterisk "**" indicates that the difference in the means is significant at $p < 0.01$. An F-statistic without any asterisk means the difference between means is not significant.*

Table 4: F-statistics and means with their standard deviations of Exchangeable acidity and EC by soil type and agroecological region

	Soil Type				Agroecological Region		
	Leptosols	Lixisols	Podzols	$F_{soil\ type}$	AER I	AER IIa	F_{AER}
Exch. Acidity (cmol(+)/kg soil)	0.19(0.14)[c]	0.57(0.29)[b]	0.62(0.19)[a]	11.80***	0.45(0.29)	0.46(0.30)	0.44
EC (µS/cm)	0.37(0.26)	0.23(0.13)	0.33(0.23)	0.93	0.38(0.21)	0.22(0.16)	5.42

*Means with the same superscripts letters within a row are not significantly different from each other. "***" indicates that the difference in the means is significant at $p < 0.001$). An F-statistic without any asterisk means the difference between means is not significant.*

Table 5: F-statistics and means with their standard deviations of soil texture by soil type and agroecological region

	Soil Type				Agroecological Region		
(%)	Leptosols	Lixisols	Podzols	$F_{soil\ type}$	AER I	AER IIa	F_{AER}
Sand	73.87(1.18)[b]	73.01(1.12)[b]	94.71(1.02)[a]	4.81*	91.15((1.05)[a]	70.55(1.13)[b]	27.92***
Clay	10.15(2.04)	11.70(1.86)	3.79(1.40)	1.75	4.59(1.56)[b]	12.19(1.94)[a]	0.04*
Silt	12.29(1.82)[a]	12.33(1.30)[a]	1.20(0.00)[b]	10.81***	2.37(2.42)[b]	14.72(1.40)[a]	7.67***

Means with the same superscripts letters within a row are not significantly different from each other. A single asterisk "" indicates that the difference in the means is significant at $p < 0.05$ and three asterisks "***" indicates that the difference is significant at $p < 0.001$). An F-statistic without any asterisk means the difference between means is not significant.*

Table 6: F-statistics and means with their standard deviations of soil water content and water retention capacity by soil type and agroecological region

	Soil Type				Agroecological Region		
(% mean rank)	Leptosols	Lixisols	Podzols	$\chi_{soil\ type}$	AER I	AER IIa	χ_{AER}
PWP	25.77[a]	26.9[a]	6.45[b]	22.32***	12.11[b]	27.96[a]	22.32***
FC	25.6[a]	27.33[a]	6.09[b]	23.48***	11.14[b]	28.72[a]	21.78***
AWHC	26.13[a]	26.87[a]	6[b]	24.3***	11.03[b]	28.8[a]	22.89***

*Means with the same superscripts letters within a row are not significantly different from each other. "***" indicates that the difference in the means is significant at $p < 0.001$).*

D. Soil texture and soil water content and retention capacity

The results show that soil texture and soil water content and retention capacity parameters are influenced significantly by soil types (Table 5 and 6). For example, percentage sand and silt fractions were significantly different among soil types, F (2, 33) = 4.81, p <0.05 and F (2, 33) = 108.11, p < 0.001, respectively (Figure 5). While Leptosols and Lixisols showed lower percentage of sand and higher percentage of silt content as shown in Table 5, Podzols exhibited higher percentage of sand and lower percentage of silt content, on comparison. Although the assumption of equality of variances as indicated by the Levene's test (p < 0.05) was violated, both the Welch-Satterthwaite and Brown-Forsythe F-test (p > 0.05) showed that the population variances between soil types were not different. At p < 0.05 and p < 0.001, soil texture was significant for percentage of sand and percentage of silt, respectively.

Soil water content and retention capacity parameters revealed significant differences among soil types (p < 0.001) for AWHC (Figure 6). The Kruskal-Wallis test for AWHC was significant (χ (2) = 24.30, p < 0.001) having the mean rank of 26.13 for Leptosol, 26.87 for Lixisols and 6.0 for Podzols as shown in Table 6, indicating that Podzols had lower AWHC when compared to Leptosols and Lixisols. The AWHC had a strong negative correlation with %sand (r = - 0.99) and a strong positive correlation with %silt (r = 0.84). A similar trend was observed when OM was correlated with texture (r = - 0.68 for %sand and r = 0.75 for %clay) and soil water content and retention capacity parameters (r = 0.65 for AWHC).

Figure 5: Comparison of average percentage particle size fraction by soil type and AER

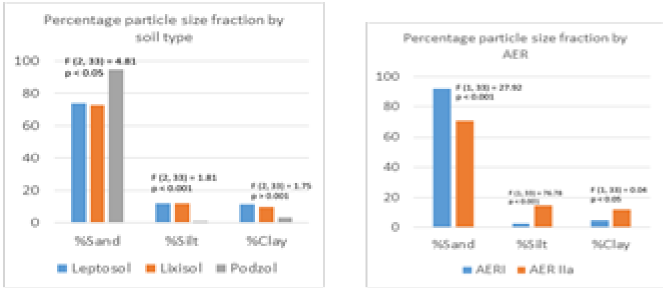
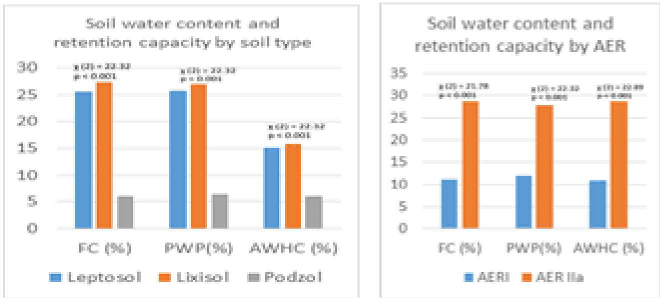


Figure 6: Comparison of average soil water content and retention capacity by soil type and AER



E. Influence of AERs on soil fertility parameters

To test the hypothesis that the AERs were associated with statistically different means of selected soil fertility parameters, a two way analysis of variance was performed. The results in Tables 2 - 6 indicate that chemical soil fertility parameters are not statistically significantly different across AERs I and IIa than physical fertility parameters. However, there is no proof to suggest that the chemical soil fertility parameters across the two AERs are the same and that blanket fertilizer recommendations are therefore suitable. However, the results seem to suggest that physical soil fertility parameters, i.e. texture and soil water content and retention capacity, are significantly different across AERs. Table 5 and 6 presents a summary of the influence of AER on texture and soil water content and retention capacity parameters.

The percentage of sand and percentage of silt content analysis for the main effect AERs yielded F ratios of F (1, 33) = 27.92, $p < 0.001$ and F (1, 33) = 76.78, $p < 0.001$, respectively, with percentage of clay yielding F (1, 34) = 0.04, $p < 0.05$. Although the assumption of equality of variances as indicated by the Levene's test ($p < 0.05$) was violated for percentage of sand, both the Welch-Satterthwaite and Brown-Forsythe test ($p > 0.05$) showed that the population variances between soil types is not different, as was confirmed by a post hoc test. The sand percentage was significantly higher in AER I (M = 92.15%, SD = 1.05) and lower in AER IIa (M = 70.55%, SD = 1.13). Significant difference in percentage of clay and percentage of silt was also observed between AER I and AER IIa (Table 5). For AWHC, the Kruskal-Wallis test was significant (χ (1) = 22.89, $p < 0.001$) with the mean rank of 11.03 for AER I, and 28.80 for AER IIa. Follow-up test showed that the mean rank is significantly different between AER I (M = 11.03) which was much lower than AER IIa (M = 28.80), U = 27.50, $p < 0.025$.

The relationship among the soil particle size fractions was found to be negative and highly significant ($p < 0.001$) as seen from the correlation matrix (Table 7). For instance, AER I had an average sand content of 91.15% and AER IIa had a mean of 70.55%. But when percentage of clay is considered, AER I had a mean of 4.59% lower than AER IIa which gave a mean of 12.19%. A similar tendency was observed in the mean percentage of silt fraction when it was compared with percentage of sand.

Table 7: Pearson correlation matrix for various soil parameters

	pH	OM	AP	TN	Sand	Clay	Silt	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	ECEC	EC	Ex. acid	AWHC	PWP	FC
pH																	
OM	0.39*																
AP	0.33*	ns															
TN	ns	ns	-0.39*														
Sand	ns	-0.68**	ns	ns													
Clay	ns	0.74**	ns	ns	-0.87**												
Silt	ns	0.49*	ns	ns	-0.88**	-0.55**											
Ca	0.46*	0.36*	ns	ns	-0.56**	ns	0.36*										
Mg	0.43*	ns	ns	ns	-0.4*	0.39*	0.38*	0.92**									
K	Ns	0.48*	ns	ns	-0.49*	0.58**	0.4*	0.47*	0.55**								
Na	0.38*	Ns	ns	ns	-0.4*	0.42*	Ns	0.79***	0.73**	0.62**							
ECEC	ns	0.36*	-0.37*	ns	-0.33*	0.56**	ns	ns	ns	ns	ns						
EC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns					
EA	-0.67**	ns	ns	ns	0.37*	ns	-0.39*	-0.65**	-0.52**	-0.38*	-0.58**	0.50***	0.42*				
AWHC	ns	0.65**	ns	ns	-0.99**	-0.84**	0.91**	0.50**	0.45*	0.48*	0.4*	ns	ns	-0.41*			
PWP	ns	0.74**	ns	ns	-0.92**	-0.85**	0.72**	0.61**		0.47*	0.42*	0.39*	ns	ns	0.89**		
FC	ns	0.67**	ns	ns	-0.91**	-0.74**	0.81**	0.50**	0.46*	0.45*	0.39*	0.36*	ns	ns	0.94**	0.87**	

(*) means the correlation coefficient is significant at $p < 0.05$; (**) means the correlation coefficient is significant at $p < 0.01$ and (***) means the correlation coefficient is significant at $p < 0.001$. Correlation coefficients that are not significant are indicated by "ns". Correlation coefficients with a negative sign have an inverse

Table 8: T-test statistics for soil parameters by AER

	Agroecological Region				
Parameter	AER I	$N_{AER I}$	AER IIa	$N_{AER IIa}$	*t-test statistic*
pH	4.70(1.11)	7	5.01(1.10)	8	-1.23
OM	1.33(0.74)	7	1.17(0.98)	7	0.35
TN	0.09(0.03)	7	0.09(0.03)	8	-0.09
AP	7.06(4.75)	6	5.41(7.40)	8	0.47
Ca	0.17(0.13)	7	0.15(0.11)	7	0.4
Mg	0.07(0.06)	7	0.14(0.07)	7	-1.81
K	0.14(0.19)	7	0.32(0.17)	7	-1.83
Na	0.72(0.58)	7	0.03(0.52)	7	2.36*
ECEC	1.23(0.89)	7	1.10(0.77)	7	0.3
Exch. Acidity	0.50(0.29)		0.47(0.30)		0.62
EC	0.06(0.05)	7	0.06(0.06)	7	0.27
Sand	79.42(10.75)	6	65.52(8.73)	8	2.67*
Clay	12.13(6.08)	7	14.88(8.99)	7	-0.67
Silt	10.69(5.47)	7	19.25(4.39)	7	-3.23
PWP	9.01(3.72)	7	12.35(4.49)	7	-1.52
FC	16.06(5.75)	7	23.08(4.47)	7	-2.55*
AWHC	0.07(0.02)	7	0.11(0.02)	7	-3.12*

Test statistic with an asterisk (*) implies the means are statistically significantly different at p < 0.05 between the two AERs.

F. Comparison of soil fertility parameters across AERs

Leptosols were the only soil type that were found in both AER I and AER IIa. To test the hypothesis that AER I and AER IIa were associated with statistically significantly different means for the selected soil fertility parameters in Leptosols, an independent samples t-test was performed. After performing some log and inverse difference transformations, the AER I and AER IIa distributions were sufficiently normal for the purpose of conducting a t-test (i.e., skewness <|2.0| and kurtosis <|9.0|; [25]. Additionally, the assumption of homogeneity of variances was tested and satisfied via Levene's F test ($p < 0.05$). The independent samples t-test was associated with statistically significant effects, t (12) = 2.67, p = 0.02 for %sand, t (12) = -3.23, p = 0.01 for %silt, t (12) = -3.12, p = 0.01 for AWHC and t (12) = 2.36, p = 0.03 for FC. Even though numerical differences in the means where observed among the other parameters, their independent samples t-test was not associated with statically significant effects (Table 8).

The results indicate that no differences in the soil chemical fertility parameters exists between Leptosols in AER I and those in AER IIa. However, soil texture and soil water content and retention capacity parameters are different between the two AERs. AER IIa exhibited higher values in silt percentage (M = 19.25%, SD = 4.39), FC (M = 16.06%, SD = 5.75) and AWHC (M = 0.11%, SD = 0.02), than AER I which had silt percentage (M = 10.69%, SD = 5.47), FC (M = 23.08%, SD = 4.47) and AWHC (M = 0.07%, SD = 0.02).

IV. Discussions

The results for soil pH are in agreement with the results of a study conducted by [26] who found the average pH on Leptosols in the study area (AER I and IIa) to be 4.86 with the recorded minimum pH value of 4.02 and a maximum of 5.06. Lungu [11] made a summary statement in a paper on fertility evaluation of soils in which he showed that acidity is a common feature of most soils in Zambia. This is especially evident when pH levels at AER level are compared overtime, as supported by the observed 20% decrease in the average soil pH seen when the mean soil pH of less than 5 observed in this study and that of Chabala at al., [26] is compared with the mean soil pH of 6.0 in soils of AER I and IIa, reported by Ballentyne [27].

The observed decrease in pH levels is as a result of induced acidity [5]. This affects nutrient availability [28] and it becomes a serious constraint to crop production. Acidity also affects the activity of soil organisms that cycle OM or fix N in legumes [29] and may cause the concentration of some elements to be toxic [30]. These factors have the potential to present serious challenges in soil fertility management because they will be influenced by soil type and AERs to different degrees, making a cross-cutting remedial measure difficult to effectively implement.

The differences in pH levels among soils, for instance, implies that nutrient availability which is strongly linked to OM decomposition will be affected differently in different soil types. For example, the results in this study show that the less acid Leptosols with the average soil pH of 4.9 have soil OM content which is two and half times more than the more acid Podzols that have a pH of 4.6. Except for AP, the other chemical soil fertility parameters (TN and Exchangeable bases) follow a similar trend. They are higher in Leptosols and Lixisols which are relatively less acid than Podzols. However, owing to the high exchangeable acidity of 0.62 cmol (+)/Kg in Podzols (Table 4), the ECEC does not follow the same trend in this instance. It therefore becomes obviously that to replenish depleted nutrients Podzols will require larger quantities of fertilizer than Leptosols and Lixisols. This, therefore, means that blanket fertilizer recommendations may not be a suitable approach if fertilizer use efficiency is to be achieved in this regard.

As regards OM content of the soils the influence of soil types may be attributed to many related factors. Firstly, there was a strong and positive correlation ($r = 0.74$) between OM and the percentage clay content of the soil at $p < 0.01$ (Table 7). Therefore the extremely low clay content in Podzols (M = 3.79%, SD = 1.40) is likely to negatively influence OM decomposition [31], [32] more than in Lixisols (M = 11.70%, SD = 1.86) and Leptosols (M = 10.15%, SD = 2.04). This implies that there is likely to be more accelerated soil OM decomposition and poor aggregate formation in Podzols than in any of the other two soils. This is because soil OM content tend to decrease as the clay content decreases as a result of the absence of sesquioxides that contribute to OM stabilization and reduction in OM turnover.

Zhao, J. et al., [33] found a positive correlation between macro aggregates and soil OM content. Therefore, it can be inferred that the relatively high soil OM content in Lixisols and to a lesser extent in Leptosols maybe a result of the presence of binding agents responsible for macro aggregate formation that prevents quick soil OM decomposition [34], [35]. This process of binding and macro aggregate formation culminates into the build-up of soil nutrient reserves. For instance, Lixisols had the highest OM content (M = 1.55%, SD = 0.55) (Table 2) and ECEC (M = 2.50 cmol (+)/Kg, SD = 0.38) (Table 3), implying that high OM content may have led to the build-up of soil nutrient reserves that releases exchangeable cations into soil solution, thereby increasing the soil ECEC.

The relationships between soil texture and AWHC parameters underscores the critical role that soil texture plays in soil water characteristics and nutrient retention linked to OM content. Studies show that low AWHC may not be conducive to biomass productivity because of the low supply of adequate moisture [36] especially under water stress, thereby disrupting nutrient supply [37]. The agronomic implications in this study are that, Podzols may not offer the best prospective as arable soils when compared with Leptosols and Lixisols because of the poor soil texture and low OM content, among others. When soil texture is poor and OM content is low, a soil loses its capacity to retain soil nutrient leading to poor soil fertility status. This, therefore, means that applying the same amount of fertilizer in Podzols as in the other two soil type may lead to fertilizer under application because Podzols have poor fertility status.

The influence of AER on soil fertility parameters indicate that AER I has low capacity to hold on to the available water in the soil than AER IIa, mainly because of the sandy soils found in the area. The soils in AER I are characteristically sandy (e.g. Podzols), and relatively young (e.g. Leptosols) which are not extremely weathered. Studies have shown that texture is an important characteristic of soil and affects water holding capacity, drainage properties, soil aeration, soil erodibility and more [38], [39], [40]. Since coarse textured soils generally tend to have larger pore spaces than fine textured soils, larger pore spaces drains faster and have less readily available water. This may lead to the reduction of nutrient movement by mass flow and diffusion [41]. During wet periods nutrient leaching in AER I is likely to be more severe than in AER IIa. This is because in the process of excessive water infiltration rate, the rate at which nutrient transport in the mobile solution takes place is likely to be faster than the rate at which it can be absorbed by plant roots.

The results of the comparison of soil fertility parameters across AERs suggests that the same fertilizer recommendation can be made for different AERs if the soils are Leptosols in both. Further research is required to be conducted on other soil types before generalized conclusions can be made.

V. Conclusions

Overall, this study has demonstrated that soil types have significant influence on soil fertility parameters that are used to determine fertilizer recommendations, than AER. The influence of soil type is more pronounced in bio-chemical soil fertility characteristics (i.e. pH, OM, TN and Exchangeable bases) than AERs whose influence tend to be more in physical soil fertility parameters (i.e. texture and soil water content and retention capacity). The results seem to suggest that blanket fertilizer recommendations across soil types and AERs are unlikely to yield to efficient fertilizer use. The measured values of soil fertility parameters belong to different classes in terms of optimality, suitability, levels of adequacy and deficiency. This means that the current blanket fertilizer recommendation may not be suitable to satisfy nutrient requirements for many crops because it does not take into account the levels of adequacy or deficiency of specific nutrients in a given soil type. Moreover, it also does not, account for the suitability of soil physical characteristics which has a critical bearing on the efficacy of fertilizer when it is applied to a soil.

The research also points to the potential value of using the differences in soil fertility parameters of soil types and AERs to develop specific fertilizer recommendations as a fundamental step towards developing precision agriculture. However, more work is required to be done to further the understanding of how the soil fertility characteristics of different soils and their interaction with AERs influence soil fertility status before generalized conclusions can be drawn.

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