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Soil Fertility Assessment of Semiarid Soils from Nigeria Cropped to Sorghum

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Authors' contributions

This work was carried out in collaboration among all authors. Authors NMD and PNK were responsible for designing the study and carrying out the necessary statistical analysis. Author NMD was responsible for preparing the first draft of the manuscript. Author KTM was responsible for financing the analysis and approval of the protocol. Author KM was responsible for writing the analytical protocol, as well as managing the analysis and preparation of data. All authors read and approved the final manuscript. All authors were involved in reviewing the final draft of the manuscript.

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ABSTRACT

The aim of this study is to characterize the fertility status of the Dingyadi soils from semiarid Northern Nigeria, by using different methods of extraction to assess the potential for soil available macro and micronutrients to the sorghum crop. The study also compared concentrations of extractable nutrients between extractants for ascertaining the possibility of using one method to quantify a variety of plant-available nutrients in soils. Surface (0-15 cm) and sub-surface (15-30 cm) soil samples were collected along a topo-sequence at Dingyadi Sokoto-Nigeria, where sorghum had been grown, to characterize the soil chemical and physical properties that can influence soil fertility for sorghum production. The topo-sequence consisted of valley floor (TLL1), middle (TUP2), and crest (TUP3) positions of the slope. At each position 60 concentrations of each plant nutrient were used for the comparisons.Soil extraction for nutrients was carried out at the Environmental Soil Physics laboratory, Soil and Water Sciences Department, University of Florida, while analysis

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of aliquots for the elements was carried out at the Southwest Florida Research and Education Center, Immokalee, Florida. The study was carried out over a period of eight months, in 2016-2017. Soil samples were extracted using different extraction methods (Mehlich-3, Bray-1, Ammonium acetate, and DI-Water). A soil to solution ratio of 1:1 was used across all extraction methods to facilitate comparison between methods. However, a test was carried out to examine the effect of soil to solution ratio of (1:10) on extractable macro nutrients using Mehlich3 for randomly selected soil samples across the topo-sequence. Soil samples were also analyzed for texture, pH, organic matter, and cation exchange capacity (CEC). All soil soils were sandy, low in organic matter content, and CEC.With respect to sorghum production, the soils had adequate nutrients (Mg, Ca, K, and P) and soil pH. All soil samples contained no exchangeable K. Mehlich3 extracted higher available P than Bray1 in TLL1, but equal amounts in TUP2 and TUP3. Good correlations exist between extracting methods for macro nutrients (Mg, Ca, K, and P). Bray1 method used for available P is not suitable for soils that have pH greater than 7 determined in water. Mehlich3 is more suitable for the semiarid soils of Northern Nigeria that are acidic or alkaline. The Mehlich3 method should be calibrated with yield response of crops to substitute for Bray1 available phosphorus. Also, Mehlich3 method could be used for the multi-nutrient test with a good correlation with other methods like ammonium acetate for exchangeable bases.

Keywords: Soil topo-sequence; soil extraction methods; soil to solution ratio; soil pH; macro and micro nutrients.

1. INTRODUCTION

Assessing soil fertility continues to hinder agricultural productivity for farmers from Sub-Saharan Africa, because of prohibitive cost and non-reliability of soil test results. In the USA, several methods are employed for the extraction and measurement of plant-available nutrients in soils. The methods include Bray1 [1], Mehlich3 [2], acid ammonium oxalate [3], and ammonium acetate. In Nigeria, research on assessment of soil fertility is mainly carried out using Bray1 [4,5,6]. Additionally, the excessive cost of reagents and analytical equipment limits the choice and frequency of collecting soil samples for soil fertility monitoring in Nigerian soils. This has resulted in the use of less conventional, and less precise means to evaluate soil fertility, such as visual plant symptoms and speculative quantification of fertility [7,8,9]. This research aims at evaluating soil fertility of the Nigerian soil samples, using different extraction methods to evaluate relationships among nutrients extracted. This will provide for inter-usability among extraction methods thereby reducing the cost of analysis for farmers and researchers.

Soils of semiarid Sokoto, Nigeria, are sandy to sandy loam, with high bulk density and the predominant soil orders areEntisols, Alfisols [10,11], and Inceptisols [10]. The Entisols and Inceptisols have been reported to have lithic contact within less than 100 cm depth, which affects drainage and plant root development [10,11]. Semi-arid soils are prone to the annual reoccurrence of a long drought spell, a part of the ecosystem [12]. Most of the time, the surfaces of the soils are bare, resulting in high evapotranspiration loss, leading to salt buildup within the root zone. For fertility management of sorghum production, the most important major nutrients are N and P [13] and to a lesser extent K. Certain secondary nutrients, Zn, Ca, S, and Mg are required as well. The key to a successful fertility regime during crop production is based on the choice of appropriate soil fertility test method and systematic tying of the method to yield of the target crop.

Most researchers in the USA currently adopt the Mehlich3 (M3) method to evaluate soil fertility because of its versatility and ability to extract macronutrients and micronutrients in soils. The Inductively Coupled Plasma (ICP) technique is generally used to measure the extracted nutrients by the M3 method. For most soil research conducted in Nigeria, however, assessment of soil fertility is done using Bray1 [6,8,10], without consideration to the suitability of the method (soil pH) for accessing the extractable plant nutrients. Also, the researchers generally restrict the application of the method to assessing available P while neglecting other nutrients extracted by the method, thereby leading to wastage of valuable information that would otherwise be available to make scientific soil fertility decisions. The M3 is considered the multi-elements extraction and assessment method [14], and data of extractable elements from the method have been used in the study of concepts of agro-environmental interests [4,15,16,17]. As a result of this, researchers in the USA have developed soil fertility interpretations for the method.

Several researchers have compared plant-available soil nutrients extracted by different extraction methods [18,19]. Most of the comparisons have been limited to P and are mainly for validation of established methods, and their critical concentrations against newly developed methods. To the best of our knowledge, no such comparison has been made for Nigerian soils. Also, no research has been identified that evaluated available P of semiarid soils of Northern Nigeria using any method other than Bray1.

This study hypothesizes that Bray1 Method of assessing available P for semiarid Nigeria soils is comparable to M3 method used for soils of humid subtropical USA. Also, that the good correlations exist among the different extraction methods, so that results from one method could be used to predict nutrients for another. If good correlations exist among the different extraction methods, this will provide for reduced cost of analyses for farmers and researchers in Nigeria where the high cost of reagents might limit undertaking evaluation assessment of soil fertility.

The main objective of this research is to characterize the fertility status of the Dingyadi soils from Nigeria, as it relates to sorghum production, by using different methods of extraction and assessment of soil nutrients. In addition, the study was set up to compare extractable nutrients across the different extraction methods to ascertain the possibility of using one method to quantify a wider variety of plant-available nutrients.

2. MATERIALS AND METHODS

2.1 Soil Sampling and Sample Preparation

Soil samples were collected from Digyadi District in Sokoto State, Nigeria. Dingyadi is an important agrarian community in Sokoto known for the production of many cash and food crops. It is located on latitude 13.93^{o}N and longitude 130.97^{o}E. The major agricultural lands of the area are located along a topo-sequence. The climate of the area is semi-arid [20], with rainfall of about 700 mm per annum distributed over 90-150 days [21]. Surface (0-15 cm) and sub-surface (15-30 cm) soil samples were collected along a topo-sequence of a previously surveyed area at Dingyadi, Sokoto, Nigeria. Soil samples were collected from the valley floor (Tulluwa lowland1, TLL1), middle slope (Tulluwa upland2, TUP2), and crest or summit (Tulluwa upland3, TUP3). Fig.1 represents the maps of Africa, Nigeria, and Sokoto State showing the study area in Bodinga Local Government. In Fig. 2, five sampling points were selected along each position on the slope. The samples were randomly collected, within a 30-m radius for every sampling point and about 150 m between sampling points for each position along the slope. A total of 60 samples per position along the slope were collected using a metal pipe of 5 cm diameter. The samples were put in water-proof Fisher brand sample bags, labeled and transported to the Environmental Soil Physics laboratory, Institute of Food and Agricultural Science (IFAS), University of Florida (UF).

2.2 Measurement of Soil Properties (CEC, pH, Soil Texture, OM)

Basic physical and chemical soil characteristics were studied using samples collected from each of the three positions along the topo-sequence. Soil pH was measured in distilled water and 0.01 M $CaCl_2$ suspensions (1:2, soil-solution ratio) by the glass electrode method [22]. Particle-size analysis was carried out by the Bouyoucos hydrometer method [23]. Bulk density and total porosity were determined following the method of Nelson and Sommers [24]. Cation exchange capacity was measured by the summation of cations from the ammonium acetate method at a pH of 7. Organic matter content was analyzed by loss on ignition [25].

2.3 Soil Fertility Assessment

Procedures described for Bray1 (1), M3 (2), and ammonium acetate extraction methods were used to assess the nutrients from all samples collected from the area. 25 mL of extraction solution was added to 25 g of air-dry soil samples in Nalgene centrifuge tubes. Another 1 g of soil (from random soil samples from the area) was added to 10 ml of solution of M3 and WSP extraction to determine the effect of soil to solution ratio on the concentration of nutrients extracted. The reason for the extraction of samples by the 1:1 soil to solution ratio across all extraction methods, was to facilitate a comparison of the methods. The mixtures were placed on an end-to-end horizontal shaker, over the specified time prescribed for each of the extraction method. The resultant mixtures were centrifuged at 5,000 revolutions per minute for 15 minutes and then filtered through a Whatman no. 40 filter paper. The aliquots were used to measure P, Fe, Al, Ca, Mg, K, and other microelements for each of the extraction methods.

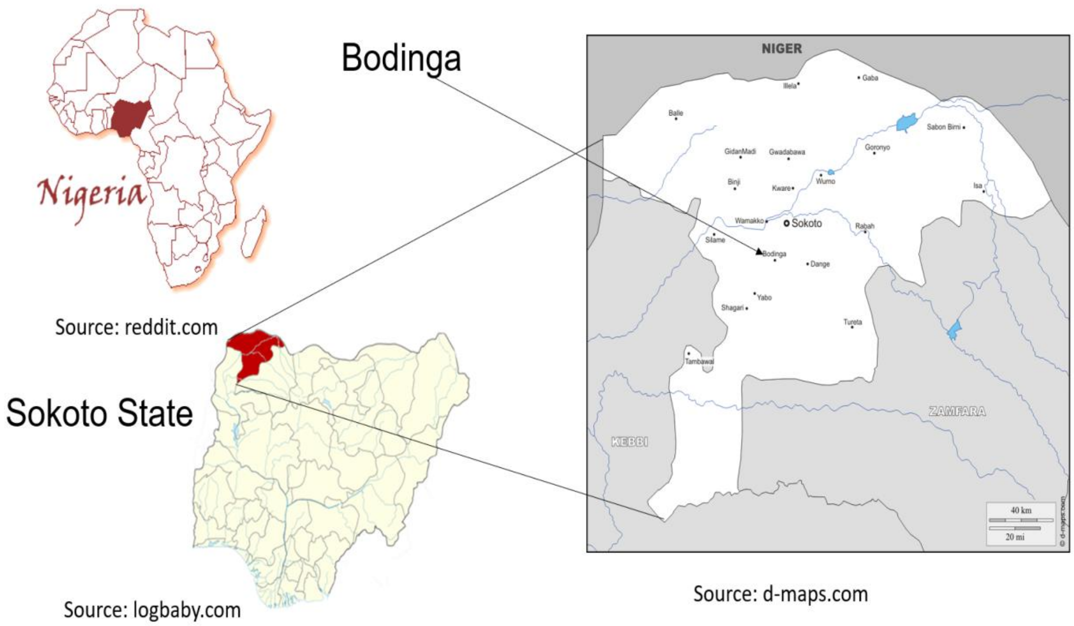

Fig. 1. Maps of Africa, Nigeria, and Sokoto State showing the study area

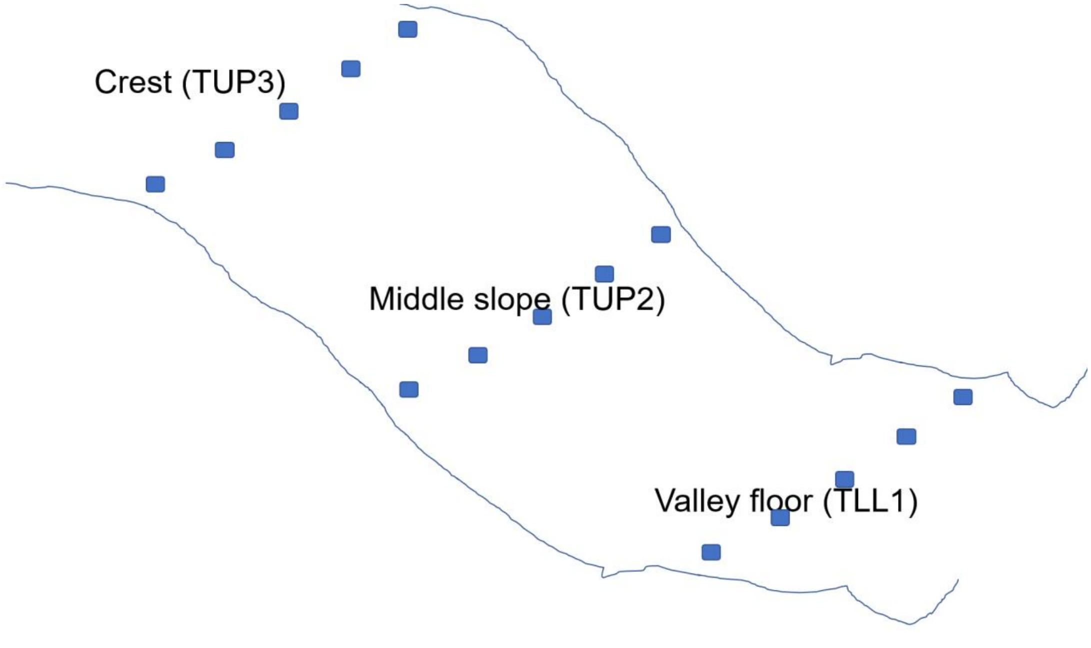

Fig. 2. Sketch of a toposequence showing sampling ponits along the slope. Each point on the slope positions represents 6 surface (0-15 cm) and 6 (15-30 cm) sampling points

2.4 Comparison of Extraction Methods

Measured extractable plant nutrients for Dingyadi soils, for the different extraction methods, were correlated against one another to find relations between the methods, and those that show prospects of use in making inferences on the fertility status of the soils (based on the correlation coefficient values) are presented. The aim here is to ascertain the possibility of using an extract from one extraction method to predict, closely, nutrients that would have been determined by using other extractants.

3. RESULTS AND DISCUSSION

Data in Table1 show a combination of interpretations of the M3 method of soil fertility assessment by Mylavarapu et al. [26], and Rutgers soil testing laboratory to interpret soil fertility for the soils used in this study. The original values were corrected using the conversion factors obtained from the effect of soil to solution ratio on M3 extractable nutrients.

3.1 Effect of Soil to Solution Ratio on Extractable Nutrients Using Mehlich3

A simple linear correlation was used to determine the effect of soil to solution ratio on the concentration of extractable nutrients by M3. The result showed that the 1:10 ratio extracted 4 times more P (R^2 = 0.73), and about 1.5 times more Ca and Mg (R^2 = 0.97 and 0.95, respectively) than 1:1 ratio. Data in Fig. 3 represent an example of the correlation between the 1:1 and 1:10 ratios for Ca. The concentrations of these nutrients were, therefore, corrected by the respective factors, using M3 method.

3.2 Soil Physical and Chemical Properties

Some basic soil properties for the Dingyadi soils are presented in Table 2. Soil texture for TLL1, TUP2 and TUP3 ranges from silt-loam to silt-clay loam, sandy loam to loamy sand, and sand to loamy sand, respectively. The pH of the soils was high (alkaline) in the TLL1 soils, and neutral to slightly acidic in the TUP2 and TUP3 soils.

Table 1. Soil test interpretation for M3 extraction method

	Mehlich3 extracted nutrient (mg/kg)		
Nutrient	Low	Medium	High
Phosphorus	≤6	7-11	≥13
Potassium	≤23	23-40	≥41
Magnesium	≤15	16-30	≥31
Calcium	≤310	310-430	≥431

Adapted from Mylavarapu et al. (2014) and https://njaes.rutgers.edu/soiltestinglab/pdfs/rellev.pdf

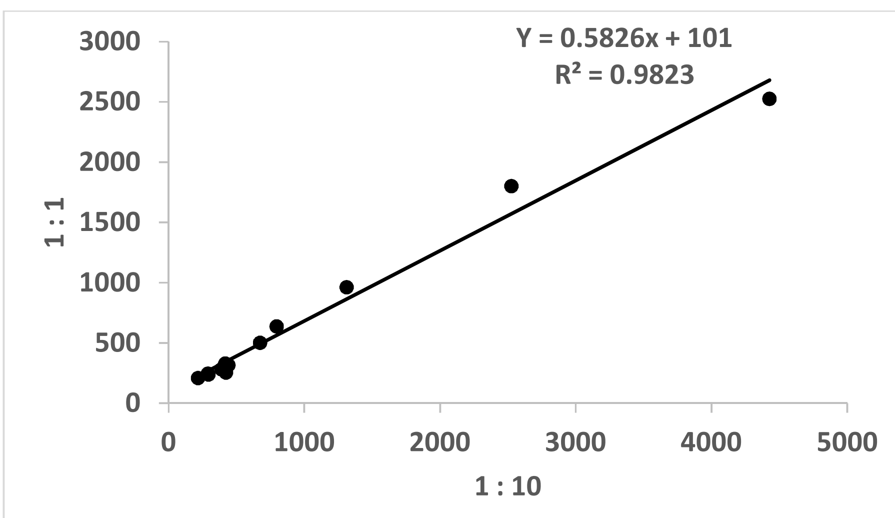

Fig. 3. Correlation between 1:1 and 1:10 soil to solution ratios on extractable calcium by mehlich3

Traditionally, pH measured in an electrolyte is less than that measured in distilled water [23,27], and this is because the electrolyte cations can displace acidic cations from exchange sites thereby lowering the pH of the solution. Minasny et al. [27] observed that the difference between pH measured in water and that measured in 0.01 M $CaCl_2$, becomes smaller as the electrical conductivity of the soil increases. In the case of these soils, it is believed that the amounts of basic cations(mainly Ca and Mg) appear to be high enough, and therefore, there are little to no exchangeable acidity in the soils (see results of exchangeable bases and also water-extractable Ca, Mg and K below). Soil pH is viewed as the most important variable in the soil because of its effect on other physical and chemical properties in the soil. Besides its effect on the availability of plant nutrients and other toxic substances, plants also vary in their ability to tolerate pH changes in the soil [28]. Sorghum is known to do well even on poor soils with low fertility, although it does best in deep, well-drained soils and pH value of 5.6 to 8.5 [29]. The effect of pH on growth and yield of sorghum has been studied by Butcheeet al.,[30]. They observed a drastic reduction in plant number for pH values below 4.3 and a slight decrease in plant number between the pH of 7.3 to 4.3 with no plant mortality with pH above 5.5. They concluded that the critical pH capable of sustaining a yield reduction threshold of 10 % is 5.42. The pH values of these soils, therefore, is optimum for sorghum production. Duncan et al.,[31] found a 96% reduction in grain yield of a hybrid sorghum when pH changed from 5.5 to 4.4. They also found a highly significant reduction in Al in soil solution with a progressive increase in pH from 4.4 to 5.5, while Mg, K, and Ca availability increased significantly. Bulk density (BD) is within a suitable range for agriculture, while soil texture was coarse. Organic matter content of the soils was very low, with all values below 1%. The low organic matter content of the soils could affect fertilizer management as the soils will have limitedorganic pool for mineralization, thereforeresulting in higher mineral fertilizer recommendations for soils with lower OM content.

3.3 Water-extractable Nutrients

The mean values of water-extractable nutrients are presented in Table 3. The data showed very low values for P and K, while quite appreciable amounts of water-extractable Ca, and Mg were observed. The values of nutrients in all soils are not different statistically (*P>0.05*), except Ca extracted from TLL1 that is different statistically (*P<0.01*). A high amount of water-soluble Ca in TLL1 may be the reason for higher pH in the soil in comparison to the other 2 soils. Mean values of water-soluble P are low in all soils.

3.4 Assessment of Soil Fertility Indices

The results of soil fertility indices are presented below. Discussions of the fertility indices, as they relate to suitability for each soil and also sorghum production, follow each presentation. A comparison among extraction methods for different elements was made to ascertain data interchangeability for the different methods.

Table 2. Some basic physical and chemical properties of the soils (0 – 30 cm)

Soil Name	Sand %	Silt %	Clay %	Textural Class	BD (g/cm^3)	OM (g/g)	pH in DI water*	pH in 0.01M* $CaCl_2$
TLL1	74	9	17	LS	1.48	0.008	7.7 ±0.3^a	7.5±0.3^a
TUP2	88	6	6	S	1.56	0.004	6.3 ±0.6^b	6.2±0.5^b
TUP3	91	6	3	S	1.57	0.004	5.6 ±0.3^c	5.4±0.5^c

**means of pH measured from 30 soils per each value. LS = Loamy sand, S= Sand, ND= Not Determined, OM=Organic Matter BD=Bulk density, DI=Deionized water*

Table 3. Average concentrations of nutrients extracted with deionized water from soils (0 to 30 cm)

	P	Fe	Ca	Mg	K
Soil			mg/kg		
TLL1	1.18±0.82^a	0.53±0.24^a	38.63±20.70^a	6.00±3.83^a	6.45±4.97^a
TUP2	0.86±0.29^a	0.40±0.06^a	17.13±9.^{03ab}	3.89±1.65^a	3.99±0.98^a
TUP3	0.95±0.77^a	0.38±0.06^a	12.67±7.18^b	5.43±2.74^a	5.99±2.52^a

Means with same superscript letters, within a column, are not significantly different (P=0.001), ±= standard deviation from the mean. TLL1= Tulluwa lowland 1, TUP2= Tulluwa upland 2, TUP3= Tulluwa upland 3

3.5 Mehlich3 Extractable Nutrients

Mean values for M3 extractable P and other macro elements are presented in Table 4. Based on Table 1, P, Ca, K and Mg contents of these soils are optimum for crop production, with Ca and Mg content on the high side for desirable crop production (see Table 1). Calcium and Mg are essential in cell wall development and increased yield [32], and increased uptake of some plant nutrients like ammonium and nitrate [33].

3.6 Ammonium Acetate Extraction (Exchangeable Bases and CEC)

Mean values for exchangeable bases, as extracted by the ammoniumacetate extractant, are presented in Table 5. The soils from the valley floor contained about 6 to 10 times more extractable bases than middle slope soils and the crest soils, respectively. Calcium and Mg dominate the exchange sites in all the soils. Cation exchange capacity, obtained by summation of exchangeable cations from the ammonium acetate extraction, was very low with the TLL1 having about 7 times and 10 times more exchangeable cations than TUP2 and TUP3, respectively. In TLL1, CEC was significantly higher (*P<0.01*) than in both TUP2 and TUP3, while TUP2 and TUP3 values were not significantly different The CEC of a soil is a measure of its productivity, as the cations held in the soil are readily exchangeable, and therefore available to plants [34]. Caravaca et al. [35] obtained CEC values that ranged from 8.6 to 41.6 $cmol_c$/kg soil for semiarid soils from Southeastern Spain, while Sharu et al. [5] calculated CEC values of between 3.28 to 4.92 $cmol_c$/kg for semi-arid soils from Sokoto, Nigeria, near the soils of this study were collected. Based on data from Table 5, ammonium acetate extractable Ca and Mg were adequate in soil samples from TLL1 and TUP2 topographic positions, while Ca is deficient and Mg is adequate for crop production in most of the samples from TUP3. Potassium content, in these soils, was very low. Also, because the ammonium acetate method extracted essentially equal amounts of K as the DI-water extraction, we concluded that the K in these soils was not exchangeable. This is most likely due to the exchange sites being dominated by Ca and Mg cations. Almost all K ions were in soil solution.

Table 4. Average concentrations of nutrients extracted by Mehlich3 method in the soils (0 – 30 cm)

	P	Ca	Mg	K
Soil		**(mg/kg)**		
TLL1	$34±19^a$	$1926±889^b$	$160±65^a$	$41±23.5^a$
TUP2	$10±5^a$	$398±150^d$	$83±29^b$	$22±3.8^{ab}$
TUP3	$9.4±5.7^a$	$210±2^e$	$52±0.1^c$	$16.2±0.1^{ab}$

Means with the same superscript letters in the same column are not significantly different (P<0.001) ± = standard deviation from the mean. TLL1= Tulluwa lowland 1, TUP2= Tulluwa upland 2, TUP3= Tulluwa upland 3

Table 5. Average concentration of nutrients extracted by ammonium acetate method in the soils

		Ca	Mg	K	CEC
Soil	**Depth (cm)**	**mg/kg**			**$cmol_c$/kg**
TLL1	0-15	1348±1219	39.5±22	6.5±6.4	$6.90±6.3^a$
TLL1	15-30	1633±1441	43.2±31	4.9±3.1	$8.59±7.4^a$
TUP2	0-15	205±71	22.0±6.8	4.6±2.0	$1.26±0.4^b$
TUP2	15-30	209±62	15.0±5.4	6.6±5.1	$1.23±0.3^b$
TUP3	0-15	121±45	12.2±4.0	8.9±4.6	$0.75±0.2^b$
TUP3	15-30	63±31	13.8±4.3	3.3±1.9	$0.49±0.2^b$

Means with superscript letters, within the same column, are not significantly different (P=0.001) ± = standard deviation from the mean. CEC= cation exchange capacity. TLL1= Tulluwa lowland 1, TUP2= Tulluwa upland 2, TUP3= Tulluwa upland 3

3.7 Bray1 (available-P)

The results for Bray 1 extraction are presented in Table 6. The data showed that Bray 1 method extracted lower concentrations of available P, and other plant nutrients, than Mehlich3 especially in location TLL1. There were wide variations in the values, for the different elements measured even within soils from the same locations (see the large standard deviations). The trend in the data showed that the valley floor soil (TLL1) contained higher concentrations of most of these nutrients than other locations. Also, the surface samples (0-15 cm) contained more concentration of the elements than the sub-surface samples (15-30 cm).

Soils samples from TLL1 site had high pH values (around 8), and Bray1 method is considered unsuitable in such soils. For this purpose, the valley floor soils were not included in the comparison of extractable elements. The method also extracted lower amounts of Mn and Zn from all soils (data not presented) when compared with M3 extraction. In the TLL1, in particular, more than 50 % of the samples did not contain any Bray1 extractable Mn, while all samples in the TUP2 and TUP3 contained some Mn. A similar trend was found for Zn in the soils. Both Mn and Zn are important micronutrients in sorghum production [36].

3.8 Comparison of Extraction Methods for P, Ca, Mg and K

Measured plant nutrients extracted from soils using the different extraction methods, were correlated with one another to find relations between nutrients obtained from extraction methods. Data in Fig. 4 represent a correlation between P measured from M3 and Bray1 extraction methods, as an example for TUP2 soil samples. Table 7 represents equations for the comparison between extractable nutrients between some extraction methods and their regression coefficients (R^2) for a given location. In assigning the dependent and independent

Table 6. Average concentration of nutrients extracted by Bray1 from soils (0 – 30 cm)

Soil	P	Ca	Mg	K
			(mg/kg)	
TLL1	9.4±5.5[a]	189±52[a]	49±15.3[a]	16.5±11.5[a]
TUP2	8.6±3.8[a]	163±44[a]	41.2±7.6[a]	9.4±2.5[a]
TUP3	10.6±4.3[a]	67±37[b]	39.5±10.5[a]	11.9±4.8[a]

Means with the same superscript letters in the same column are not significant statistically (P=0.001) ± = standard deviation from the mean. CEC= cation exchange capacity.
TLL1 = Tulluwa lowland 1, TUP2 = Tulluwa upland 2, TUP3 = Tulluwa upland 3.

Table 7. Regression equations for comparison of some nutrients for the different extractions

Analyte	Soil	Y-axis	X-axis	Equation	R^2
P	TLL1	M3	Bray1	Y=1.89x+9.19	0.2606
P	TUP2	M3	Bray1	Y=1.04X-0.04	0.7427
P	TUP3	M3	Bray1	Y=0.92X-0.91	0.6057
Ca	TUP2	Bray1	M3	Y=0.27X+39.62	0.4818
Ca	TUP3	Bray1	M3	Y=0.27X+16.60	0.6036
Mg	TLL1	Bray1	M3	Y=0.16X+23.66	0.7409
Mg	TUP2	Bray1	M3	Y=0.22X+15.22	0.2755
K	TLL1	Bray1	M3	Y=0.43X-1.29	0.8542
Ca	TLL1	M3	NH4-AC	Y=0.81X+798	0.8285
Ca	TUP2	M3	NH4-AC	Y=2.26X-37	0.8389
Ca	TUP3	M3	NH4-AC	0.59X+157	0.1022
Mg	TLL1	M3	NH4-AC	Y=2.56X+47	0.8495
Mg	TUP2	M3	NH4-AC	Y=3.00X+26	0.5786
Mg	TUP3	M3	NH4-AC	Y=3.55X+12	0.7711

M3= Mehlich3, AC= Acetate, M3= Mehlich3, NA= not applicable, TLL1= Tulluwa lowland 1, TUP2= Tulluwa upland 2, TUP3= Tulluwa upland 3.

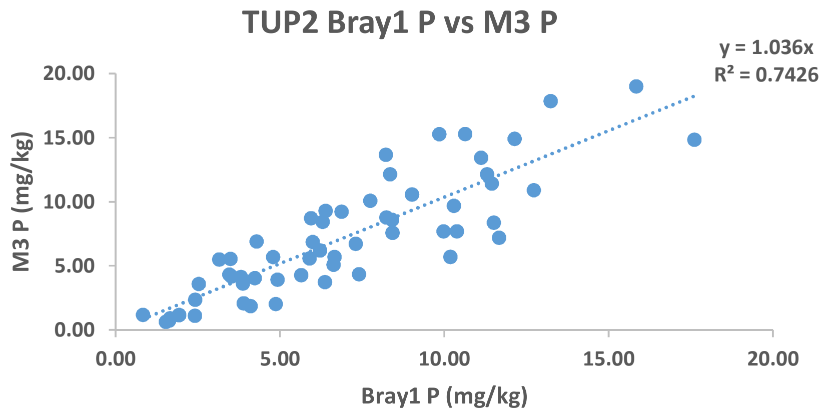

Fig. 4. Regression analysis between Mehlich3 (M3) and Bray1 extractable P

variables in the regression analyses, the X-axis wasdesignated to the main method normally used to assess the analytes. The number of samples compared in each relationship is 60. The data showed that M3 and Bray1 extracted equal quantities of P from all soils, except in TLL1. The TLL1 extractable nutrients using Bray1 method did not correlate well with any of the extraction methods. Bray1 method is not suitable for measuring plant nutrients in the soil from the valley floor because of alkaline pH values of the soil (Table 2). The relationship, in terms of Ca, was similar to that of P in the soils, further attesting to the pH being the reason for the poor relation between M3 and Bray1 in TLL1. The data showed a good relationship between M3 and ammonium acetated extractable Ca and Mg (except in TUP3-Ca) with the M3 extracting about 3 to 5 times more of the bases than ammonium acetate. However, there was statistically no good correlation between the methods in terms of K in all soils. Nathan et al. [20] compared extractable phosphorus from some extraction procedures and found that M3 extracted about 50% more P than Bray1 for about 97% of 162 soil samples from Missouri. Based on the results of the correlations between nutrients from different extraction methods, it was inferred that the extractable nutrients from some extraction methods could be used, interchangeably, for rapid evaluation of soil fertility in the soils studied.

4. CONCLUSION

The soils were sandy with low organic matter content. Soil pH ranged from alkaline (in the valley floor soil) to slightly acidic (in the crest soil). The soils had adequate pH, Ca, Mg, and P for sorghum production. Bray1 method used for available P in Nigeria, is not a suitable in the valley floor soil that has alkaline pH. Mehlich3 method is more suitable for assessing the fertility of all soils. A substantial amount of Ca and Mg was extracted from the soils by M3 method. However, the soil to solution ratio used with M3 method affects the concentration of extracted macro nutrients (P, Ca and Mg). The soils contain very low water-soluble P compared to P extracted by other methods, implying that the soils have high sorption capacity for P. The data show good correlations between different extraction methods for macronutrients (P, Ca, and Mg). Therefore we concluded that the methods could be used, interchangeably, for rapid evaluation of soil fertility of semiarid soils from Northern Nigeria.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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