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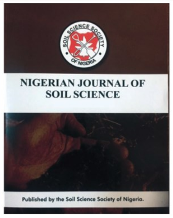

Magnesium Forms in Bulk and Grain Size Fractions of Soils of Contrasting Land-uses in Imo State, Southeastern Nigeria

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ABSTRACT

Magnesium contents in bulk and grain size soil fractions from 2 soil depths (0-20 and 20-40 cm) of 5 land uses (Yam, fluted pumpkin, cassava, pineapple and plantain) in three locations (Amuzari, Umuaka and Ngor-Okpala) in Imo state were evaluated. Total, mineral/structural, acid extractible/non-exchangeable, exchangeable, water-soluble and available Mg were subjected to ANOVA and means separated using LSD at 5% probability. The correlation between bulk soil Mg and bulk soil Mg with selected soil properties were determined using correlation analysis. The relationship between bulk and grain size soil Mg was determined using regression analysis. Total, mineral/structural, acid extractible/non-exchangeable, exchangeable, water-soluble and available Mg ranged from 5.47-12.44, 1.30-2.35, 1.91-3.08, 1.29-8.13, 0.23-1.40 and 2.18-9.73 cmol kg^{-1} in decreasing order of total > available > exchangeable > mineral/structural > acid extractible > soluble Mg and differed significantly (LSD 0.05) with land-uses and soil depths. Whereas concentrations and enrichments of total and available Mg were better in clay, mineral/structural, acid extractible/non-exchangeable, exchangeable, and water-soluble Mg were in the sand fraction. Also, the correlation amongst most Mg forms was significant ($P < 0.05$), while that between bulk soil Mg with soil properties was not. Finally, besides acid extractible/non-exchangeable Mg in bulk soil, more than 50% of bulk soil Mg was accounted for by the grain size contents, with clay fraction contributing much of the impact. Knowledge of bulk and grain size soil Mg status could be useful for its efficient and sustainable management in soils.

1.0 Introduction

Widespread magnesium deficiency has been reported in most sub-Saharan African soils, making it one of the crop's most limiting nutrients (Yan and Hou, 2018; Vona et al., 2020). Causes of the deficiency have been ascribed to poor soil management, intense weathering, leaching, fixation, absence of Mg minerals, intense cultivation, growth of high Mg demanding crops and competition between Mg with Ca^{2+}, NH_4^+ and K^+ (Craighead, 2001; Jayaganesh et al., 2011; El-Dissoky et al., 2017). It has been noted that Mg deficiency occurs mostly in low ECEC highly leached acidic sandy soils, inherently low Mg calcareous soils, low Mg limed acidic soils, soils fertilized with high rates of NH_4-N and K fertilizer and those cultivated with high Mg demanding crops (Havlin et al., 2012). Magnesium deficiency in plants manifests as premature defoliation, interveinal chlorosis, poor photosynthetic processes and growth reduction (Gransee and Fuhrs, 2013). In Nigeria and sub-Sahara Africa, efforts at addressing soil Mg deficiency often involved the inclusion of Mg in most fertilizer formulations. This has, however, not yielded desired results as applications are often made without knowledge of the soil test levels. Thus, an inventory of the soil Mg status could be useful for efficient and sustained Mg management. Magnesium plays significant roles in physiological processes of chlorophyll formation, protection against abiotic stress conditions and co-factor in most enzymatic processes, especially phosphorylation, dephosphorylation, hydrolysis and stabilization of nucleotide structures (Klieber et al., 2012; Gansee and Fuhurs, 2013; Senbayram et al., 2015; Yan and Hou 2018). Also, it promotes cell turgor, protein, fat and carbohydrate synthesis, cation-anion balance, cellular pH and carbon dioxide assimilation (Craighead, 2001; El-Dissoky et al., 2017). Equally, it is associated with poor soil aggregation, porosity, infiltration and high surface sealing (Mikkelsen, 2010; Ogbonna et al., 2013) and, together with Ca, helps neutralize soil acidity and its associated biota activities, promotes mobility of metal, phosphorus and other nutrients (Katutis and Rudzianskaite 2015).

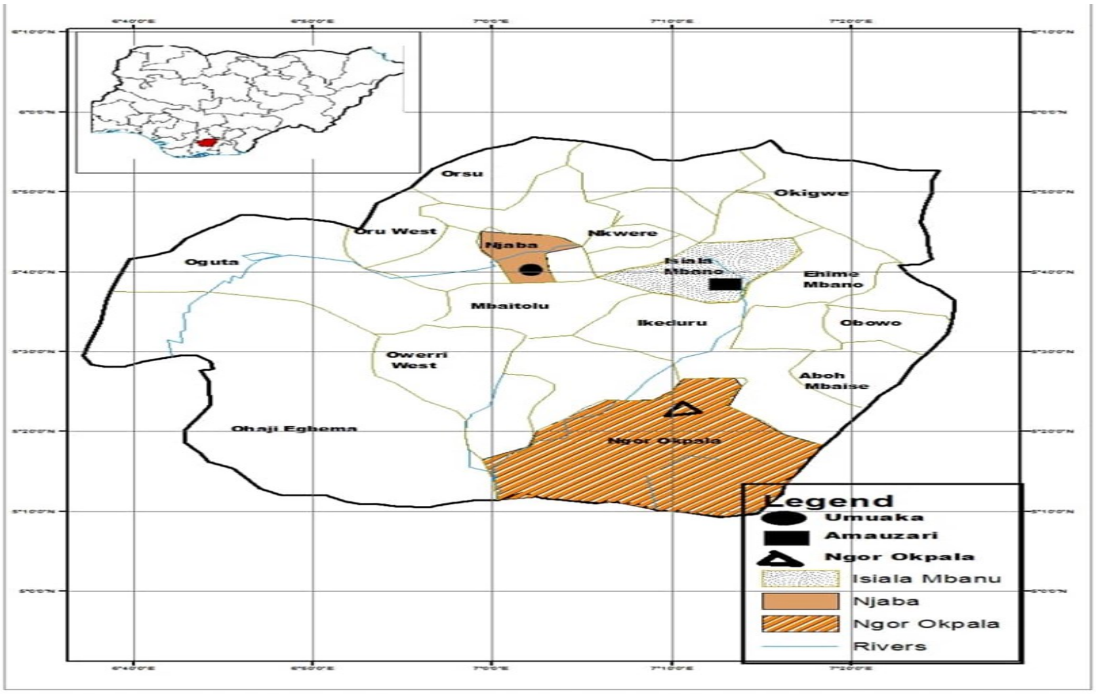
Sources of Mg in soils include mineral weathering, organic matter decomposition, liming and Mg fertilization (Havlin et al., 2012).Its total concentration varies between 0.1% (8.33 meq/100 g soil) in coarse-textured humid soils to 4% (333.33 meq/100 g soil) in fine-textured arid or semiarid soils formed from Mg-rich parent materials (Havlin et al., 2012). It also includes about 5 mg kg^{-1} or 0.05-0.5% in soils (Senbayram et al., 2015; Yan and Hou, 2018) or 7.35-12.60 (mean = 9.65+.0.79 cmol kg^{-1}) in Central Southern Nigeria soils (Osenwota et al., 2007). Total soil Mg has been partitioned into several operationally defined forms as water-soluble, exchangeable, non-exchangeable and structural/mineral Mg (Craighead, 2001; Jayaganesh et al., 2011; Klieber et al., 2012; Okpamen et al., 2013; Vona et al., 2020). Water-soluble fractions are available in soil solution and easily lost through the plant or microbial uptake and leaching (Osenwota et al., 2007). Exchangeable Mg constitutes about 3-20% of total Mg present in a diffuse double layer, or electrostatically adsorbed onto negatively charged soil solid phase, and in direct equilibrium with soil solution phase (Vona et al., 2020), non-exchangeable or slowly exchangeable fraction consists of specifically bound Mg to organic matter/humic substances, carbonates, Fe/Mn hydroxides or present in octahedral and interlayer clays of varying hydration (Mikkelsen, 2010) while structural/mineral fraction constitutes about 90-98% of total Mg that are present in lattices of primary and secondary minerals (Klieber et al., 2012; Senbayram et al., 2015). It has been noted that solution Mg is usually buffered by the readily available form, which is replenished by exchangeable and then structural Mg (Marschner et al., 1995). Thus, knowledge of Mg forms in soils is useful for its sustained management of crops and environmental health.

Several biotic and abiotic factors, especially land use, affect soil Mg (Gransee and Fuhrs, 2013; Okpamen et al., 2013) and include, for instance, decreased water-soluble, available, exchangeable, non-exchangeable and mineral Mg in soils of tea relative to forest land-uses (Jayaganesh et al., 2011). According to Olorunfemi et al. (2018), land-use impacts include changes in soil properties, alteration in chemical forms and distribution of nutrients via soil organic matter, pH, clay and submergence. These include a significant and positive correlation between Mg with clay, OM, ECEC but pH and a non-significant but positive relation with pH on cultivated and forest land use, respectively (Hailes et al., 1997; Jayaganesh et al., 2011). It also includes decreased Mg with K^{+}, Ca^{+} and NH$_4^{+}$ due to antagonism and competition (Jayaganesh et al., 2011) and poor correlation between exchangeable Mg with OM, pH, clay, and structural and total Mg (Senbayram et al., 2015). Equally, it includes a non-significant correlation between Mg with soil properties (Osenwota et al., 2007) and a significant correlation of exchangeable Mg with pH, OM, CEC and Ca (Lombin, 1979; Okpamen et al., 2013). Metals, especially Mg distribution, vary with soil grain size fractions and include, for instance, high K in the sand (Najafi-Ghiri and Abtahi et al., 2013), silt (Igwe et al., 2008), clay fractions (Ajibade and Ogunwale, 2012), heavy metals in clay (Sayadi et al., 2017), B in silt (Tlili et al., 2019), P and micronutrients in clay (Uzoho,2018; Uzoho and Ironkwe, 2020) and sesquioxides in sand fractions (Uzoho et al., 2019). These variations have been attributed to differences in soil specific surface areas, negative charges and organic matter content (Scherer et al., 2012; Sayadi et al., 2017; Tlili et al., 2019). It has been noted that the finer the soil particles, the greater their surface area and adsorptive capacity (Sayadi et al., 2017; Tlili et al., 2019). Knowledge of ion or Mg distribution in grain size soil fractions is useful for soil stabilization against microbial degradation and thus valuable for efficient soil management. The present study's main objective was to determine Mg distribution in bulk and grain size soil fractions and predict bulk soil from grain size contents in soils of selected land uses in Imo State, Southeastern Nigeria.

2.0 Materials and Methods

2.1 Study Locations

Study locations included Ngor-Okpala (Imo East), Umuaka (Imo West) and Amuzari (Imo North) in the three agricultural zones of Imo State (Fig. 1) that is delineated by differences in vegetation, rainfall, topography and parent materials as in agricultural zones of Southwestern Nigeria (Salami and Sangoyomi, 2013). Umuaka is situated in the Orlu agricultural zone and lies between Latitudes 5^0 27' 30" and 5^0 39' 13" N and Longitudes 7^0 02' 21" and 7^0 06' 00" E in the humid rainforest vegetation of southeastern Nigeria, with an annual rainfall range of 1657.4-2114.7 mm, the daily temperature of 19.97-32.73^{0}C, relative humidity of 72.62-81.08% and on an elevation of 104 mm above sea level (IPEDC, 2006). Its soil type varies depending on land use and includes Arenic Kandiudult and Typic Paleudult (USDA 2004) on Coastal Plain Sands and Alluvial parent materials. Main crops grown in the area include plantain (Musa spp), cassava (Manihot Utilis), fluted pumpkin (Telferia occidentalis), pineapple (Ananas spp), oil palm (Elaeis guinensis), cashew (Anacardium occidentale), Rubber (Hovea Braziliensis), yam (Dioscorea spp), maize (Zea mays) etc. with the major economic activities being farming, trading, hunting, artisanry, civil service and sand mining. Ngor-Okpala in Owerri agricultural zone lies between Latitudes 5^0 22' 19" and 5^0 25' 8" N and Longitudes 7^0 08' 51" and 7^0 13' 40" E in the tropical rainforest vegetation zone of Southeastern Nigeria and with a landmass of 635.75 km^2. Its mean annual rainfall ranges from 2202.3-2206.2 mm, mean daily temperature of 27.81- 39.22^{0}C and relative humidity of 70.62-81.08% and 73 mm above sea level (IPEDC, 2006). The soil types included Ruptic Hapludult and Typic Paleudult (Uzoho et al., 2007) on Coastal Plain Sands (Benin formation) parent materials of the Oligocene-Miocene geological era that are deeply weathered, kaolinitic with low exchangeable bases, base saturation and cation exchange capacity (Lekwa and Whiteside, 1986). The commonly grown crops include fluted pumpkin (Telferia occidentalis), cassava (Manihot esculentum), maize (Zea mays), melon (Cucumis melo), plantain (Musa spp), yam (Dioscorea spp), okra (Hibiscus esculentum), pineapple (Ananas spp)oil palm (Elaeis guineensis) and rubber (Hovea braziliensis). Its primary economic activities include farming, trading, artisanry and civil service.



Amauzari is situated in Okigwe agricultural zone and lies between Latitudes 5^0 24' 02" and 5^0'39' 21" N and Longitudes 7^0 02' 29" and 7^0 06' 41" E with a mean annual rainfall range of 2200-3000 mm, mean daily temperature of 26 -35 ^{0}C and annual relative humidity of 65-85% (IPEDC, 2006). The soil type is Ultisol derived from Coastal Plain Sands (Orajiaka, 1975) on an elevation of 132 mm above sea level. Main crops grown include fluted pumpkin (Telferia occidentalis), yam (Dioscorea spp), cocoa-yam (Colocasia esculenta), pineapple (Ananas spp), rice (Oryza sativa), plantain (Musa spp), cassava (Manihot esculemtum), melon (Cucumis melo), green amaranth and maize (Zea mays) and cashew (Anacardium occidentale), oil palm (Elaeis guinensis) with major economic activities being farming, trading, sand mining, civil service and artisanry

2.2 Soil Sampling and Preparations

Five land uses (Pineapple, fluted pumpkin, plantain, cassava and yam) common to the three locations (Amuzari, Umuaka and Ngor-Okpala) were selected for the study, with the land uses constituting the treatments and the locations, the replicates are given a total of five and three treatments and replications respectively. The pineapple landuse consisted of 2-4 years old pineapple orchards mulched using elephant grass (panicum maximum), Christmas plants (Abbemesa odoratum) and oil palm (Elaeis guinensis) fronds and fertilized with poultry and hog manures, the fluted pumpkin (Telferia occidentalis) consisted of < 1 - $2^{1/2}$ years old vegetable farms located around homesteads and fertilized with household (kitchen) wastes and inorganic manures (NPK 20:10:10) and staked using bamboo and Acio bateri sticks, plantain farms varied between 2-8 years plantations maintained using organic and inorganic manures, yam farm was a 3-5 months old farm cultivated mainly on plots formerly under fallow for 3-4 years while the cassava farm was a 7-12 months farms on ridges, mounds and flats fertilized using combinations of organic and inorganic fertilizers, especially NPK Mg 15:15:17: 3 fertilizers. In each land use, soil samples were collected from 0-20, 20-40 and 40-60 cm depths and air-dried, sieved using 2 mm diameter mesh and the fine earth particles were stored in clean dry polybags.

2.3 Soil fractionation and Laboratory Analyzes

Subsamples of the fine earth soil fractions were then fractionated into sand (0.2-2.0 mm), silt (0.02-0.2 mm) and clay (< 0.002 mm) fractions using the method described by Sequaris and Lewandowski (2003), while the remaining portions were subjected to laboratory analyses using standard methods. Mechanical analysis was conducted using the hydrometer method (Gee and Or, 2002), pH in 1:2.5 soil/ water ratio using glass electrode of the pH meter, exchangeable cation and ECEC (Thomas, 1996), total N (Bremner, 1996) and organic matter (Nelson and Sommers, 1996). Magnesium forms in bulk, and particle size soil fractions from 0-20cm (topsoil) and 20-60cm (subsoil) depths were determined using the following methods. Total Mg (Jackson, 1958), non-exchangeable/acid extractable Mg (Pratt, 1965), exchangeable Mg using 1N NH_4OAC (Thomas, 1996), water-soluble fraction using distilled water and Mineral/structural Mg as a difference between total Mg and summation of all other Mg fractions. All extractions were made in duplicates, and the Mg was determined using Atomic Absorption Spectrophotometer model EAA Analyst 200, Perkin Elmer Wellesley, MA, USA.

2.4 Statistical Analysis

All Mg data generated were subjected to analysis of variance and means separated using LSD at 5% probability. The correlation between selected soil properties and bulk soil Mg fractions was determined using correlation analysis, while the relationship between bulk soil and particle size Mg was determined using regression analysis. All analyzes were conducted using Genstat statistical package (GENSTAT, 2005).

3.0 Results and Discussion

3.1 Soil Characterization

Mean sand, silt and clay contents ranged from 689.33-717.14, 61.44-72.90 and 209.95-242.67 g kg^{-1} (Table 1), with sand greater than others probably due to the nature of the parent materials which are Coastal Plain Sands and

Table 1. Physicochemical Properties of Soils of Selected Land uses

Land use	Depth	Sand	Silt	Clay	SCR	OC	TN	Ca	K	ECEC	pH
	cm	g kg^{-1}				g kg^{-1}		Cmol(+)kg^{-1}			
Cassava	0-20	782.00	74.00	142.00	0.52	2.86	0.24	3.58	0.31	9.69	5.89
	20-40	644.00	67.00	289.00	0.23	2.60	0.22	3.27	0.24	3.72	5.73
	40-60	650.00	53.00	297.00	0.18	1.45	0.12	2.24	0.22	3.34	5.56
	Mean	692.00	64.67	242.67	0.27	2.30	0.12	3.93	0.26	5.58	5.72
Yam	0-20	745.00	76.24	178.76	0.43	2.62	0.21	4.89	0.23	5.65	5.92
	20-40	696.00	63.42	240.58	0.26	2.15	0.18	3.91	0.17	4.41	5.62
	40-60	657.34	44.66	298.00	0.15	1.57	0.13	3.43	0.15	3.05	4.93
	Mean	699.45	61.44	239.11	0.26	2.11	0.17	4.40	0.18	4.37	5.47
Pineapple	0-20	756.00	45.24	198.76	0.23	2.09	0.17	1.14	0.25	6.97	5.86
	20-40	676.00	78.15	245.85	0.32	1.96	0.16	1.05	0.18	4.69	5.82
	40-60	636.00	82.23	281.77	0.29	1.78	0.15	1.01	0.16	3.93	5.16
	Mean	689.33	68.54	242.13	0.28	1.94	0.16	1.30	0.20	5.20	5.61
Plantain	0-20	856.24	46.14	97.62	0.47	4.18	0.35	2.56	0.26	5.89	6.02
	20-40	766.23	78.27	155.50	0.50	2.62	0.21	1.72	0.16	4.15	5.55
	40-60	674.26	78.89	246.85	0.32	1.57	0.13	1.61	0.12	4.34	5.23
	Mean	765.58	67.77	166.66	0.41	2.79	0.23	3.61	0.18	4.79	5.59
Fluted Pumpkin	0-20	756.63	82.14	161.23	0.51	2.83	0.23	8.74	0.27	6.05	6.32
	20-40	698.64	76.15	225.21	0.34	2.47	0.20	7.31	0.21	3.97	6.26
	40-60	696.16	60.42	243.42	0.25	1.69	0.14	7.25	0.16	6.04	5.71
	Mean	717.14	72.90	209.95	0.35	2.33	0.19	7.77	0.21	5.35	6.09

Alluvium (Obi, 2015; Abam and Orji, 2019).

Silt/clay ratios were less than unity indicating highly weatherability and old age (Abam and Orji, 2019). Also, the silt/clay ratios were above 0.15 in all land uses, suggesting low weathering intensity potentials (Yakubu and Ojanuga, 2013). Soils were slight to moderately acidic (Adaikwu and Ali, 2013), with pH values greater than 5.0, indicating that they are not likely to suffer from aluminium toxicity (Uzoho et al., 2007). Due to poor litter accumulation, intense burning, grazing and rapid decomposition of organic materials, the soil organic carbon was low and below the critical limit for southeastern Nigerian soils (Enwezor et al., 1990). Also, the poor organic matter content probably accounted for the low soil N, P, Ca, K and ECEC since the fertility of tropical soils depends on the organic matter contents (Uzoho et al., 2007).

3.2 Soil Magnesium

Mean total Mg in bulk soil ranged from 5.47-12.44 cmol kg^{-1}, equivalent to 656.4 -1492.60 mg kg^{-1} or 0.66 -1.492 g kg^{-1} and comparable with values of 370-1550 mg kg^{-1} for Indian forest soils (Jayaganesh et al., 2011), 7.35-12.60 cmol kg^{-1} for south-central Nigeria surface soils (Osenwota et al., 2007) and Nigerian savanna soils (Lombin, 1979) but high relative to 228-968 mg kg^{-1} for cultivated Indian soils (Jayaganesh et al., 2011) and 300-8000 mg kg^{-1} for Australian soils (Hailes et al., 1997). Its concentration was significantly (LSD 0.05) higher in plantain, and the topsoil (9.41) than in subsoil (7.55 cmol kg^{-1}) of the land uses studied (Table 2). Mean distribution amongst particle size fractions was better in topsoil, with sand and silt fractions significantly higher in plantain while the clay was in pineapple land-use. Also, its mean concentration and enrichment were better in clay (7.32 and 0.93) than in sand (6.05 and 0.74) and silt (4.16 cmol kg^{-1} and 0.57) fractions averaged over land uses and soil depths.

Structural/mineral Mg, the fraction of primary and secondary minerals that vary with hydration rates (Kleiber et al., 2012), ranged from 1.30-2.35 cmol kg^{-1} or 156.00-282.00 mg kg^{-1} and 0.16-0.28 g kg^{-1} equivalent to 18.90-31.81% of total Mg in the bulk soil studied (Table 3). This is comparable to a range of 90-352 mg kg^{-1} for Indian lateritic soils (Jayaganesh et al., 2011) but low relative to 2.94-5.04 cmol kg^{-1} for south-central Nigerian soils (Osenwota et al., 2007) and about 90-98% total Mg in soils (Senbayram et al., 2015). Its mean concentration was significantly (LSD 0.05) better in cassava (2.35 cmol kg^{-1}), and topsoil (1.74 cmol kg^{-1}) of the land uses (Table 3).

Table 2. Total magnesium (cmol+kg-1) in Bulk and Particle Size Fractions of Soils of the various Land uses

Land uses	Soil Depth	Bulk Soil	Particle Size Fractions			Enrichment Factors		
	cm		Sand	Silt	Clay	Sand	Silt	Clay
Cassava	0-20	6.03	4.00	2.62	5.26	0.66	0.43	0.87
	20-40	6.00	4.29	3.64	4.36	0.72	0.60	0.73
	Mean	6.02	4.15	3.13	4.81	0.69	0.51	0.80
Yam	0-20	7.92	4.12	4.36	6.44	0.52	0.55	0.81
	20-40	3.01	3.64	3.11	3.67	1.21	1.03	1.22
	Mean	5.47	3.88	3.74	5.06	0.86	0.79	1.02
Pineapple	0-20	7.54	3.83	3.94	11.22	0.51	0.52	1.49
	20-40	12.46	3.21	2.57	12.84	0.26	0.21	1.03
	Mean	10.00	3.52	3.26	12.03	0.38	0.36	1.26
Plantain	0-20	12.48	23.11	7.40	11.27	1.85	0.59	0.90
	20-40	12.40	6.25	5.88	10.23	0.50	0.47	0.83
	Mean	12.44	14.68	6.64	10.75	1.17	0.53	0.87
Fluted Pumpkin	0-20	13.07	4.60	4.65	3.82	0.35	0.36	0.29
	20-40	3.87	3.44	3.44	4.12	0.89	0.95	1.06
	Mean	8.47	4.02	4.05	3.97	0.62	0.65	0.68
LSDs (0.05)	Fact A	1.55	2.45	0.61	1.47	0.19	0.10	0.13
	Fact B	0.98	1.55	0.39	0.93	0.12	0.06	0.08
	Fact A x B	2.20	3.46	0.86	2.08	0.27	0.14	0.18

Fact A = Land use, Fact B = Soil depth

Table 3. Mineral/Structural Magnesium (cmol+kg-1) in Bulk and Particle Size Fractions of Soils of the various Land uses

Land uses	**Soil Depth**	**Bulk Soil**	**Particle Size Fractions**			**Enrichment Factors**		
	cm		Sand	Silt	Clay	Sand	Silt	Clay
Cassava	0-20	2.37	1.84	0.57	0.96	0.78	0.24	0.41
	20-40	2.33	1.95	1.33	1.05	0.84	0.56	0.45
	Mean	2.35	1.90	0.95	1.01	0.81	0.40	0.43
Yam	0-20	1.71	1.44	1.26	0.86	0.84	0.74	0.50
	20-40	1.19	1.52	0.98	0.49	1.28	0.82	0.41
	Mean	1.45	1.48	1.12	0.68	1.06	0.78	0.46
Pineapple	0-20	1.90	1.25	1.37	0.28	0.66	0.72	0.15
	20-40	1.14	1.26	1.16	0.73	1.11	1.01	0.64
	Mean	1.52	1.26	1.26	0.51	0.89	0.87	0.40
Plantain	0-20	1.46	2.16	0.69	1.04	1.08	0.35	0.52
	20-40	1.14	1.44	1.20	0.63	1.26	1.05	0.54
	Mean	1.30	1.80	0.95	0.84	1.17	0.70	0.53
Fluted Pumpkin	0-20	1.27	0.86	0.45	0.00	0.68	0.35	0.00
	20-40	1.74	0.77	0.32	1.43	0.44	0.18	0.82
	Mean	1.51	0.82	0.39	0.72	0.56	0.27	0.41
LSDs (0.05)	Fact A	0.19	0.18	0.16	0.17	0.11	0.13	0.09
	Fact B	0.12	0.11	0.10	0.11	0.07	0.08	0.06
	Fact A x B	0.27	0.26	0.22	0.24	0.16	0.18	0.13

Fact A = Land use, Fact B = Soil depth

Distribution amongst particle fractions was a high topsoil sand (1.51) and subsoil silt (1.00), and clay (0.87 cmol kg^{-1}) contents and with the sand (1.90) and clay (1.01) fractions distinctly better in cassava, while silt (1.26 cmol kg^{-1}) was in pineapple land use. Also, averaged over land uses and soil depths, mean concentration and enrichment in the sand fraction (1.45 cmol kg^{-1} and 1.17) were better than others.

Mean acid extractible/non-exchangeable Mg in bulk soil was distinctly better in plantain (3.08 cmol+kg^{-1}) and the topsoil (2.81) than in subsoil (1.97 cmol+kg^{-1}) of the land uses (Table 4), with a range of 1.91-3.08 cmol+kg^{-1} which is low relative to 2.52 – 5.25 cmol+kg^{-1} for south-central Nigeria surface soils (Osenwota et al., 2007). Mean particle size concentrations were better on top than subsoil, with sand fraction superior to others. Also, amongst land uses, mean sand (2.06 cmol+kg-1) and silt (2.23) contents were distinctly higher in plantain while clay (2.12) was in cassava. Equally, mean concentrations and enrichments in the sand were better than the other grain fractions averaged over land uses and soil depths.

Mean bulk soil exchangeable Mg ranged from 1.29-8.13 cmol kg^{-1} (154.80-975.6 mg kg^{-1} or 0.15 – 0.98 g kg^{-1}), equivalent to 23.58-65.35% total Mg (Table 5) and constitutes the fraction present in the diffused double layer or electrostatically adsorbed to negatively charged soil solid phase (Erp, 2002). This range is high compared to some highly weathered lateritic Indian soils (Jayaganesh et al., 2011), central-southern Nigerian surface soils (Osenwota et al., 2007), Nigerian savanna soils (Lombin 1979) and 3-20% total Mg for soils (Kleiber et al., 2012; Vono et al., 2020). It is also high relative to the potential of the critical limit of 1.20 cmol kg^{-1} for southeastern Nigeria soils (Enwezor et al., 1990), thus suggesting no probable soil deficiency. Mean distribution in the soils was significantly (LSD 0.05) better in pineapple land-use and the subsoil (4.58) than topsoil (4.32 cmol kg^{-1}). Similar, high sub than topsoil concentrations have been reported for some highly weathered and aged Indian soils (Jayagenesh et al., 2011). Amongst particle size fractions, mean sand (10.40) and silt (3.21) contents were better in plantain, while clay (9.16 cmol kg^{-1}) was in pineapple land-use. Also, its enrichment averaged over land uses, and soil depths were better in the sand fraction (0.82). Mean water-soluble Mg ranged from 0.23-1.40 cmol kg^{-1} (27.00-168.00 mg kg^{-1} or 0.027-0.168 g kg^{-1}), equivalent to 4.20-11.25% of total Mg in bulk soil (Table 6) and high relative to 1.70-6.40 and 3.80-9.00 mg kg^{-1} for tea and forest soils respectively in India (Jayaganesh et al., 2011) but comparable with most Delta and Edo states soils of Nigeria (Okpamen et al., 2013).

Table 4. Acid Extractable Magnesium (cmol+kg-1) in Bulk and Particle Size Fractions of Soils of the various Land uses

Land uses	Soil Depth	Bulk Soil	Particle Size Fractions			Enrichment Factors		
	cm		Sand	Silt	Clay	Sand	Silt	Clay
Cassava	0-20	2.81	1.74	1.62	2.07	0.62	0.58	0.74
	20-40	2.06	1.91	2.31	2.16	0.93	1.12	1.05
	Mean	**2.44**	**1.83**	**1.97**	**2.12**	**0.78**	**0.85**	**0.90**
Mixed Farm	0-20	2.31	1.83	2.55	1.73	0.79	1.10	0.75
	20-40	1.50	1.32	1.01	0.74	0.88	0.67	0.49
	Mean	**1.91**	**1.58**	**1.78**	**1.24**	**0.84**	**0.89**	**0.62**
Pineapple	0-20	3.04	2.10	1.72	1.84	0.69	0.57	0.61
	20-40	1.74	1.55	1.17	1.49	0.89	0.67	0.86
	Mean	**2.39**	**1.83**	**1.46**	**1.67**	**0.79**	**0.62**	**0.74**
Plantain	0-20	3.18	2.68	1.83	1.67	0.84	0.58	0.53
	20-40	2.98	1.44	2.63	0.91	0.48	0.87	0.31
	Mean	**3.08**	**2.06**	**2.23**	**1.29**	**0.66**	**0.73**	**0.42**
Fluted Pumpkin	0-20	2.70	2.26	1.82	0.71	0.84	0.67	0.26
	20-40	1.55	1.81	0.00	1.66	1.17	0.00	1.07
	Mean	**2.13**	**2.04**	**0.91**	**1.19**	**1.01**	**0.34**	**0.67**
LSDs (0.05)	Fact A	1.10	0.16	0.32	0.21	0.08	0.13	0.11
	Fact B	0.07	0.10	0.20	0.14	0.05	0.08	0.07
	Fact A x B	1.55	0.23	0.45	0.30	0.11	0.18	0.16

Fact A = Land use, Fact B = Soil depth

Table 5. Exchangeable magnesium (cmol+kg-1) in Bulk and Particle Size Fractions of Soils of the various Land uses

Land uses	Soil Depth	Bulk Soil	Particle Size Fractions			Enrichment Factors		
	cm		Sand	Silt	Clay	Sand	Silt	Clay
Cassava	0-20	1.60	0.62	0.00	0.98	0.39	0.00	0.61
	20-40	0.98	0.00	0.00	0.78	0.00	0.00	0.80
	Mean	**1.29**	**0.31**	**0.00**	**0.88**	**0.20**	**0.00**	**0.71**
Yam	0-20	4.49	0.63	0.36	3.47	0.14	0.08	0.77
	20-40	3.40	0.57	0.72	2.09	0.17	0.21	0.61
	Mean	**3.95**	**0.60**	**0.54**	**2.78**	**0.16**	**0.15**	**0.69**
Pineapple	0-20	6.28	0.00	0.35	8.35	0.00	0.06	1.33
	20-40	9.97	0.00	0.00	9.97	0.00	0.00	1.00
	Mean	**8.13**	**0.00**	**0.18**	**9.16**	**0.00**	**0.03**	**1.17**
Plantain	0-20	6.14	17.60	4.71	8.24	2.87	0.77	1.34
	20-40	6.11	3.11	1.71	7.60	0.51	0.28	1.24
	Mean	**6.13**	**10.40**	**3.21**	**7.92**	**1.69**	**0.53**	**1.29**
Fluted Pumpkin	0-20	3.11	1.19	1.58	2.61	0.38	0.51	0.84
	20-40	2.45	0.62	2.80	0.63	0.26	1.14	0.26
	Mean	**2.78**	**0.91**	**2.19**	**1.62**	**0.32**	**0.83**	**0.55**
LSDs (0.05)	Fact A	1.10	2.19	0.62	1.48	0.35	0.16	0.14
	Fact B	0.07	1.38	0.39	0.93	0.22	0.10	0.09
	Fact A x B	1.55	3.09	0.88	2.09	0.49	0.22	0.20

Fact A = Land use, Fact B = Soil depth

Table 6. Water Soluble Magnesium (cmol+kg-1) in Bulk and Particle Size Fractions of Soils of the various Land uses

Land uses	Soil Depth	Bulk Soil	Particle Size Fractions			Enrichment Factors		
	cm		Sand	Silt	Clay	Sand	Silt	Clay
Cassava	0-20	0.98	0.40	0.43	1.25	0.41	0.44	1.28
	20-40	0.80	0.43	0.00	0.37	0.54	0.00	0.46
	Mean	**0.89**	**0.42**	**0.22**	**0.81**	**0.48**	**0.22**	**0.87**
Yam	0-20	1.00	0.22	0.19	0.38	0.22	0.19	0.38
	20-40	0.80	0.23	0.40	0.35	0.29	0.50	0.44
	Mean	**0.90**	**0.23**	**0.30**	**0.37**	**0.26**	**0.35**	**0.41**
Pineapple	0-20	1.80	0.48	0.50	0.75	0.27	0.28	0.42
	20-40	1.40	0.40	0.25	0.65	0.29	0.18	0.46
	Mean	**1.60**	**0.44**	**0.38**	**0.70**	**0.28**	**0.23**	**0.44**
Plantain	0-20	1.20	0.67	0.17	0.32	0.56	0.14	0.27
	20-40	1.60	0.26	0.34	1.09	0.16	0.21	0.68
	Mean	**1.40**	**0.47**	**0.26**	**0.71**	**0.36**	**0.18**	**0.48**
Fluted Pumpkin	0-20	1.60	0.29	0.80	0.50	0.18	0.50	0.31
	20-40	1.20	0.23	0.55	0.40	0.19	0.45	0.33
	Mean	**1.40**	**0.26**	**0.68**	**0.45**	**0.19**	**0.48**	**0.32**
LSDs (0.05)	Fact A	0.14	0.18	0.16	0.13	0.11	0.13	0.09
	Fact B	0.09	0.11	0.10	0.08	0.07	0.08	0.06
	Fact A x B	0.20	0.26	0.22	0.19	0.16	0.18	0.13

Fact A = Land use, Fact B = Soil depth

Concentrations were significantly better in pineapple (1.60) land-use and the top (1.32) than subsoils (1.16) studied. Amongst particle size fractions, mean distribution in the sand (0.47), silt (0.68), and clay (0.81) fractions were better in plantain, fluted pumpkin and cassava land-uses, respectively and in topsoil than the subsoil. Also, concentration and enrichment of the clay fraction were better averaged over land uses and soil depths.

Available Mg consisting of exchangeable and water-soluble fractions (Okpamen et al., 2013) ranged from 2.18-9.73 cmol kg$^{-1,}$ equivalents to 39.85-78.22% of total Mg in the bulk soil (Table 7). This is high relative to the critical available Mg range of 0.2-0.4 cmol kg^{-1} reported by Lombin (1979) in Guinea Savanna soils suggesting that Mg is not limiting in the soils. Mean concentrations were better in pineapple (9.73) land-use and the subsoil (5.74 cmol+kg^{-1}) depths. Amongst particle size fractions, mean sand (10.87) and silt (3.47) were better in plantain while the clay was in pineapple (9.88 cmol+kg^{-1}) land-use. Equally, averaged over land-uses and soil depths, its enrichment was better in the clay fractions.

In general, Mg distribution in the soils decreased in the order total Mg (8.48) > available (5.69) > exchangeable (4.46) > non-exchangeable/acid extractible (2.39) > mineral/structural (1.63) > water-soluble (1.2488 cmol+kg^{-1}), with available consisting of water-soluble and exchangeable Mg forms constituting much of total Mg. Other workers have, however, reported better exchangeable Mg (Vona et al., 2020) and structural/mineral Mg forms (Hailes et al., 1997; Okpamen et al., 2013). High topsoil concentration in most soil fractions could be due to its high organic matter accumulation (Okpamen et al., 2013). Also, the distribution and enrichment in grain size soil fractions have been reported for other nutrients (Sayadi et al., 2017; Uzoho,2018; Uzoho et al., 2019; Tlili et al., 2019; Uzoho and Ironkwe, 2020). Its high concentration in clay fraction could be due to high specific surface area since this increases with increased fine particle size (Sayadi et al., 2017).

Table 7. Available magnesium (cmol+kg-1) in Bulk and Particle Size Fractions of Soils of the various Land uses

Land uses	**Soil Depth**	**Bulk Soil**	**Particle Size Fractions**			**Enrichment Factors**		
	cm		Sand	Silt	Clay	Sand	Silt	Clay
Cassava	0-20	2.58	1.02	0.43	2.23	0.80	0.44	1.89
	20-40	1.78	0.43	0.00	1.15	0.54	0.00	1.26
	Mean	2.18	0.73	0.22	1.69	0.68	0.22	1.58
Mixed Farm	0-20	5.49	0.85	0.55	3.85	0.36	0.27	1.15
	20-40	4.20	0.80	1.12	2.44	0.46	0.71	1.05
	Mean	4.85	0.83	0.84	3.15	0.42	0.50	1.10
Pineapple	0-20	8.08	0.48	0.85	9.10	0.27	0.34	1.75
	20-40	11.37	0.40	0.25	10.62	0.29	0.18	1.46
	Mean	9.73	0.44	0.56	9.86	0.28	0.26	1.61
Plantain	0-20	7.34	18.27	4.88	8.56	3.43	0.91	1.61
	20-40	7.71	3.37	2.05	8.69	0.67	0.49	1.92
	Mean	7.53	10.87	3.47	8.63	2.05	0.71	1.77
Vegetable	0-20	4.71	1.48	2.38	3.11	0.56	1.01	1.15
	20-40	3.65	0.85	3.35	1.03	0.45	1.59	0.59
	Mean	4.18	1.17	2.87	2.07	0.51	1.31	0.87
LSDs (0.05)	Fact A	1.18	2.23	0.64	1.50	0.38	0.19	0.17
	Fact B	0.75	1.41	0.40	0.95	0.24	0.12	0.11
	Fact A x B	1.67	3.15	0.90	2.13	0.54	0.27	0.24

3.3 Relationships amongst Bulk Soil Mg Forms, between bulk soil Mg with Selected Soil Properties and bulk and Grain Size soil Mg

The correlation between Mg forms and bulk soil Mg with selected soil properties and the relationship between bulk and grain size soil Mg are presented in Table 8, figure 1 and Table 9, respectively. In Table 8, correlation amongst most bulk soil Mg were significant (P <0.05) exception being correlation between Mineral/structural Mg with available Mg (r = -0.07), acid extractible/non exchangeable Mg (r = - 0.12), exchangeable (r = -0.12) and water-soluble Mg (r = 0.29). Other workers have noted a positive and significant correlation between total Mg with water-soluble and exchangeable Mg, acid extractible/non-exchangeable with exchangeable Mg and water-soluble Mg, exchangeable with water-soluble Mg and between non-exchangeable with total Mg (Jayaganesh et al., 2011). Equally, the relationship between Mg with soil properties (Fig. 1) showed a linear relationship between total Mg with clay, ECEC, pH and Ca, but OC, the inverse relationship of mineral/structural Mg with clay, OC, pH, ECEC and Ca, linear of exchangeable Mg with OC, pH, ECEC and Ca but clay. It also includes the linear relationship between water-soluble and available Mg with OC, ECEC and Ca but clay and pH. The linear and inverse relationship indicates that as the soil properties increased, soil Mg equally increased or decreased respectively. In general, Mg correlated poorly with the properties of the soils studied. In a related study, a positive and significant correlation has been reported between water-soluble Mg with OM and ECEC, but pH in cultivated and no significant (P < 0.05) correlation between Mg forms with soil properties of forest land use in India (Jayaganesh et al., 2011). Finally, the relationship between bulk and grain size Mg contents indicates that besides acid extractible/non-exchangeable Mg (12%) and mineral/structural Mg (53%), more than 60% of bulk Mg was accounted for by the grain size soil Mg contents, with the clay fraction playing a significant impact as indicated by its coefficients.

4.0 Conclusions.

It could be concluded that the soils studied were highly weathered, old, coarse-textured, acidic, low in OC and with multiple nutrient deficiencies. Total and Mg forms differed with land-use and soil depths, with exchangeable, water-soluble and available Mg being high in pineapple, total and acid extractible/non-exchange Mg in plantain and mineral Mg in cassava land-uses. Also, exchangeable and available Mg, all others were better in the topsoil. Amongst grain size fractions, concentrations and enrichments were better in the clay fraction.

Table 8. Inter-Correlation between Mg forms in the Studied Soils

	Avail. Mg	Total Mg	Min. Mg	Acid Ext. Mg	Exch. Mg
Total Mg	0.73**				
Min. Mg	-0.07	0.05			
Acid Ext. Mg	0.99**	0.69**	-0.12		
Exch. Mg	0.99**	0.69**	-0.12	1.00**	
Water Sol. Mg	0.73**	0.74**	0.29	0.65**	0.65**

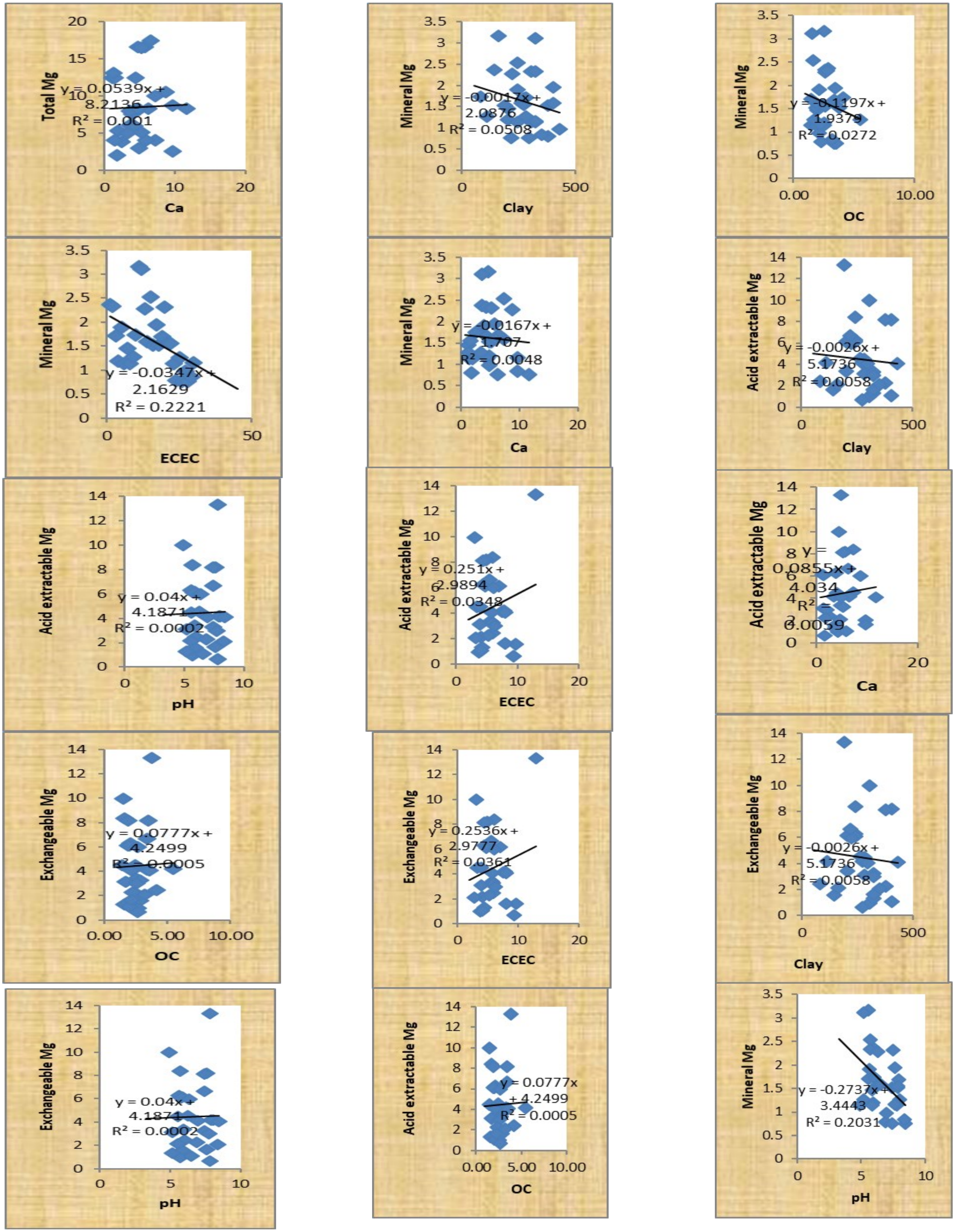


Fig 1a. Relationship between Mg forms and selected Soil Properties

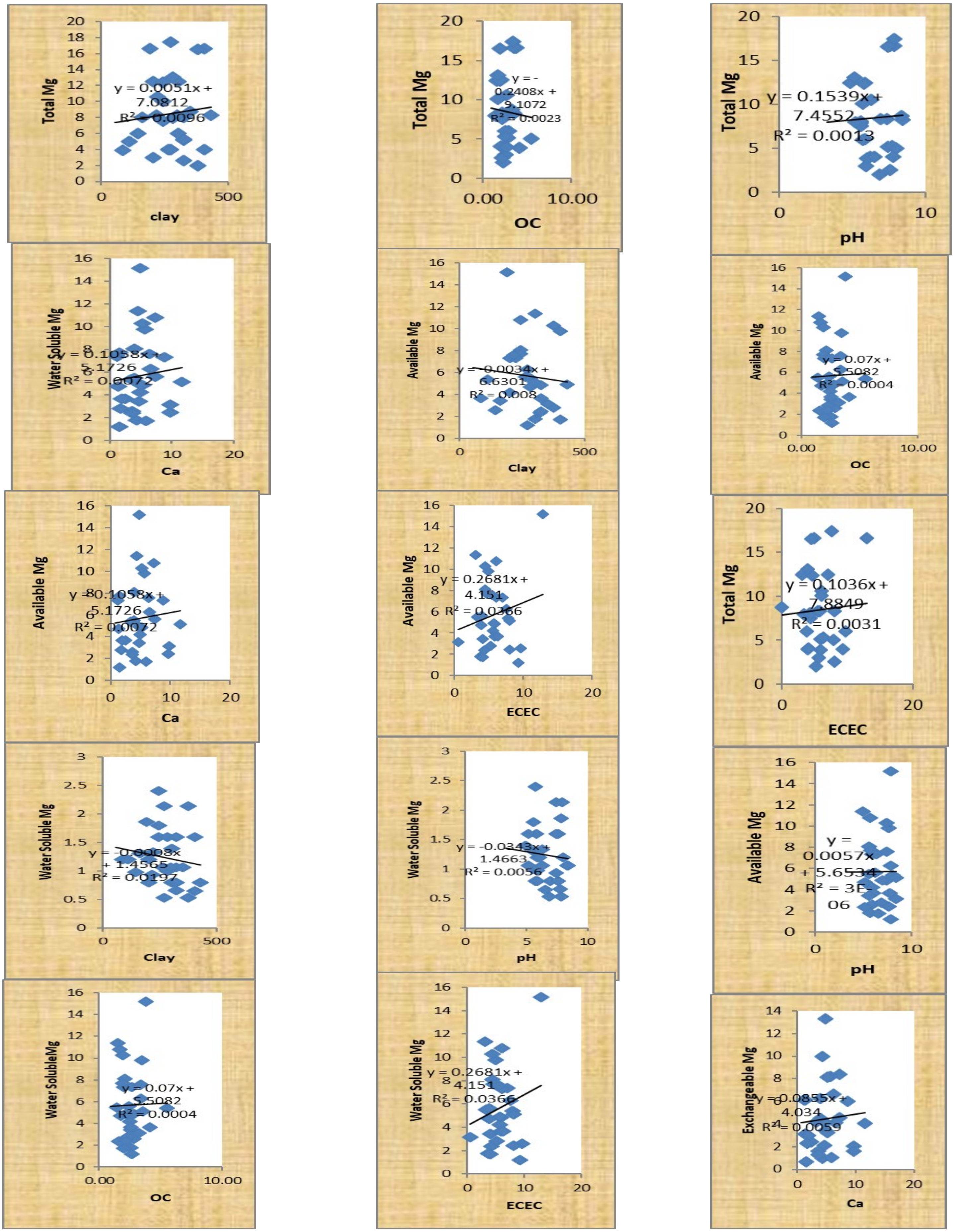


Fig 1b. Relationship between Mg forms and selected Soil Properties

Table 9. Relationship between Bulk Soil and Particle Size Soil Mg

Variables	Regression Equation	R	R^2	Sign.
Total Mg	$Y_{tMg} = 1.50\ silt_{tMg} + 0.52\ Clay_{\ tMg} - 0.17\ sand_{\ tMg} - 0.53$	0.82	0.67	0.0000
Mineral/Mineral Mg	$Y_{mMg} = 0.44 + 0.42\ sand_{mMg} + 0.21\ silt_{\ mMg} + 0.52\ Clay_{\ mMg}$	0.73	0.53	0.0002
Acid Extractible Mg	$Y_{aex.\ Mg} = 1.82 + 1.47\ sand_{aex\ Mg} + 0.46\ silt_{aex\ Mg} - 0.58\ Clay_{aex.\ Mg}$	0.35	0.12	0.339
Exchangeable Mg	$Y_{eMg} = 0.89 - 0.16\ sand_{\ e\ Mg} + 0.34\ silt_{\ eMg} + 0.79\ Clay_{\ e\ Mg}$	0.96	0.92	0.0000
Water Soluble Mg	$Y_{wsMg} = 0.21 + 1.21\ sand_{wsMg} + 1.11\ silt_{wsMg} + 0.31\ Clay_{wsMg}$	0.82	0.67	0.000
Available Mg	$Y_{av\ Mg} = 1.10 - 0.20\ sand_{av\ Mg} + 0.50\ silt_{av\ Mg} + 0.86\ Clay_{av\ Mg}$	0.97	0.94	0.0000

t = total, m = mineral, aex = Acid extractible/non-exchangeable, e = Exchangeable, ws = Water Soluble and av = Available

Also, whereas correlation amongst most soil Mg was significant, that with soil properties was poor and non-significant, indicating that contribution of the soil properties to the Mg was minimal. Finally, besides acid extractible/non-exchangeable Mg, grain size soil Mg accounted for more than 50% of the bulk soil concentrations, with clay fraction playing a significant influence.

5.0 References

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