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Characterization of Selected Gypsites of Tanzania for Agricultural Use

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Authors' contributions

This work was carried out in collaboration between all authors. Author AMP designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors EMMM and AKK edited the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This study was carried out to assess the suitability of gypsite as a soil amendment in the release of Ca and S. Besides the high potential of gypsite in improving crop yields in some countries, its use in Tanzanian agricultural soils is limited. This is attributed largely due to few types of research on their agricultural potentials. The gypsite samples used in this study were collected from Pindiro, Makanya, Itigi and Msagali sites. The X-ray fluorescence (XRF) method was employed to analyse the chemical compositions of the composite samples. The XRF results showed that the gypsites from the four sites varied in amounts of gypsum content from 35.76 to 82.36% for gypsite from Itigi and Pindiro, respectively. The contents of S were 15.32, 13.26, 10.52 and 6.65% for Pindiro, Msagali, Makanya and Itigi gypsites respectively. Calcium contents were 11, 9.5, 7.6 and 4.8% for Pindiro, Msagali, Makanya and Itigi gypsites, respectively. Analysis on extractable nutrients shows that when gypsite from Pindiro and Msagali that contained a high amount of S and Ca when applied in the soil, plants will be able to extract different nutrients for their metabolism at the same time improving soil physical properties. All the studied gypsite samples contain potentially toxic elements (Cd, Co, Cr, Cu, Fe, Mn, Ni and Zn), but the levels are not potentially toxic to plants and hence do not interfere with plant nutrient uptake.

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Characterization of gypsite from other deposits in the country is required to generate information on their quality, quantity and suitability for use on soil amendment for increased agricultural productivity in Tanzania.

Keywords: Gypsite, soil; amendment; nutrient; mineral.

1. INTRODUCTION

Tanzania is an agricultural country, and the livelihoods of nearly 80% of Tanzanians depend directly or indirectly on subsistence rain-fed agriculture [1]. Agriculture contributes about half of Tanzania's gross national product (GNP) and provides about 90% of the rural employment [2]. Although agriculture is the backbone of the Tanzanian economy, crop productivity is generally low as a result of a number of factors; among them salinity, drought, pest and disease infections, genetic variability, poor soil management and inadequate macro- and micro-nutrients in the soils [3].

Increasing the productivity of agricultural soils is essential to sustainably supply food, feed, fuel, and fiber for a growing human population. The demand for increased productivity has resulted in the search for alternative soil management practices to increase crop yields, using gypsum as a management tool to improve crop yields and soil is essential. Gypsum's benefits as a plant nutrient source and soil conditioner for agricultural production have been known dating back to the late 18th century [4]. Chen and Dick [5] reviewed the use of a soft calcium sulfate dihydrate mineral ($CaSO_4{\cdot}2H_2O$), in agriculture and for other land applications.

Gypsite is a rock that contains an abundance of the mineral gypsum ($CaSO_4.2H_2O$) [6]. It is naturally occurring as a soft rock in association with limestone, silica, clays and a variety of soluble salts as impurities along with other trace elements, such as copper, zinc, nickel, iron and manganese. These trace elements are not usually found in hard rock gypsum deposits. Under high pressure and temperature, gypsum turns into anhydrite ($CaSO_4$) [7]. Pure gypsum ($CaSO_4{\bullet}2H_2O$), is composed of 79% calcium sulfate ($CaSO_4$) and 21% water (H_2O). Pure gypsum contains 23.3% calcium (Ca) and 18.6% sulphur (S) [7]. Gypsum is moderately soluble in water (2.5 g L^{-1}) or approximately 200 times higher than agricultural lime ($CaCO_3$) [8] . This makes the calcium in gypsum more mobile than the calcium in lime and allows it to easily move through the soil profile where it can provide nutrients to deep plant roots and help to alleviate subsoil nutrient availability problems.

Gypsite has various benefits in the soil as well as in plants including supplying calcium (Ca) and sulphur (S) for plant nutrition [9]. Plants require relatively large amounts of calcium and sulphur because Ca is needed at 0.5% shoot dry weight and S is needed in a range of 0.1 to 0.5% dry weights for optimal growth [10]. Gypsum can provide many physical and chemical benefits to soils in addition to nutritional benefits. It increases subsoil Ca [11], decreases subsoil acidity [12] and reduces exchangeable aluminium (Al) [13,14].

With respect to soil physical properties, the benefits of gypsum when used as soil amendment include increased water infiltration [15;16], increased soil aggregation [16], decreased Na adsorption, improved or increased root development [17] and reduced soil compaction. Other benefits are an increase in the hydraulic conductivity of soil after consecutive gypsum applications [16], and a reduction in metal toxicities has also been documented [18; 19]. Most farmers in Tanzania do not use sulphate fertilisers as a source of nutrients in soils. In the long run, this is causing a deficiency of sulphur in soils. Introduction of high yielding crop varieties, intensive and multiple cropping, the decreased use of farmyard manures, removal of crop residues for feed and fuel, leaching, burning, erosion, microbial and plant uptake, a more significant proportion of S may be unavailable to plant. The above processes seem to have led to a wide occurrence of S deficiency in soils for plant uptake [20,21].

Sulphur (S) deficiencies in soils of tropical and subtropical regions have been recognised for many years [22]. Sulphur deficiency has been reported from over 70 countries, including Tanzania.For instance, corn (*Zea mays* L.) removes approximately 18 kg ha^{-1} to 40 kg ha^{-1} for silage and 12 Mg ha^{-1} grain harvest [23]. The combination of reduced inputs and increased S removal from soil has sparked interest in evaluating responses of crops to gypsum additions. In S deficient conditions, the efficiency of applied N, P_2O_5 and K_2O, may be severely affected and high yields may not be sustained [24]. The consequence of this trend in most parts of the country is a decrease in crop production. Inorganic fertilisers in Tanzania are not obtained at the right time and are at higher costs, which are not affordable to smallholder farmers who are primarily producing for subsistence [25]. This also was reported by Kimbi, et al. [26] that water-soluble fertilizers are expensive to resource-poor farmers, so farmers could benefit more by using agro minerals, namely gypsite rocks as sources of S and Ca because the country is endowed with large quantities of gypsite deposits [27], these could be used as alternative sources of nutrients in crop production. Low soil fertility and high nutrient mining are among the main factors limiting crop yields in Sub-Saharan Africa [28], Tanzania inclusive [29]. Some soil fertility management technologies being used to address low soil fertility in Tanzania include the use of organic soil amendments (e.g., crop residues, animal manures, agroforestry tree pruning) and inorganic (fertilisers, agro-minerals) resources [30] and commercial products such as bio-fertilisers and chemical products. Agro-minerals have improved crop yields in some countries, but in Tanzania the use of gypsites in agriculture as a source of plant nutrients is limited, and this could be due to lack of enough research on their potential suitability. Duarah, et al. [31] reported that excessive and improper application of industrial fertilisers imposes residual impact to soils, so the use of agro-minerals such as a gypsite rock in agriculture can be one of the alternative means of assisting farmers to replenish the soils with sulphur without causing harm to plants. Apart from adding sulphur in the soil, gypsite rocks could also supplement the soil with calcium.

2. MATERIALS AND METHODS

2.1 Description of Gypsite Sampling Sites

Gypsites were collected from four Districts; these are Makanya located in Same District, with coordinates of latitude 4°15’S and longitude 37°55’E, Msagali situated in Mpwapwa District, Dodoma in Tanzania. It is located at latitude 6°45'S and longitude 36°20'E. [32].

Itigi is situated in Manyoni, in Singida District, Tanzania. Its geographical coordinates are latitude 5°42' 0" South and longitude 34°29' 0" East and Pindiro is located in Kilwa District latitude 9°29’44” S and longitude 39°18’36” E. Is the most northerly District in the Lindi Region of southern Tanzania.

2.2 Sampling of Gypsite

Five composite samples of gypsite were randomly collected from each site including Pindiro, Msagali, Itigi and Makanya. The collected samples were then placed in labelled polyethylene bags and transported to Soil Science Laboratory at Sokoine University of Agriculture, Morogoro Tanzania where the determination of nutrients extractability was conducted. Some samples were taken to Geological Survey of Tanzania Laboratory in Dodoma, where the determinations of the chemical compositions were carried out.

2.3 Laboratory analysis

The samples were processed and prepared for laboratory analysis following standard procedures. Chemical compositions of the collected gypsite rocks were determined by using X-ray Fluorescence (XRF) method by the use of XRF machine model: PW4030 with Rh tube and spinner [33].

Samples were crushed to reduce the size and then mixed well and ground to pass through 75 microns sieve. The ground samples were put in a cup covered with polyesterpetp X-ray film 9430 500 07191 at the bottom and compressed. The samples were then placed into a calibrated XRF machine for analysis. Analysis was done by using *Minipal Analytical Software* at the Geological Survey of Tanzania in Dodoma.

2.4 Determination of Loss on Ignition

Porcelain crucibles were heated in the laboratory furnace for 1 h at 100°C, and then crucibles were taken out of furnace with tongs and placed into desiccators to cool at room temperature. The weight of crucibles was taken and noted down in the notebook. One gram of each sample was weighed into the crucible and put into the cool furnace then heated to 900°C for 1 h. Samples were placed in desiccators and cooled at room temperature and thereafter reweighed. Loss on ignition (L.O.I) was calculated by using the formula:

$$\text{L.O.I}\ (\%) = \frac{M_0 - M_1}{M_0 - M_c} \times 100$$

Whereas M_o = original mass of sample + crucible; M_1 = mass of ignited sample + crucible; and Mc = mass of ignite crucible

Results are shown in Table 1

2.5 Determination of the Extractability of Sulphur, Calcium, Magnesium and Potentially Toxic Elements (PTEs) from Gypsites

Gypsite rock samples were ground to pass through 0.5 mm sieve to ensure the increase in surface area. Extractable sulphur was determined by using $BaCl_2$ turbidimetric method and measurement was done using UV Spectrophotometer [34]. Calcium and magnesium were determined in the neutral ammonium acetate leachate (NH_4OAc, pH 7) saturation method and quantified by atomic absorption spectrophotometry. Extractable potentially toxic elements (PTEs) were extracted using buffered 0.05 M DTPA (Diethylenetriamine penta acetic acid) and their concentrations were determined by Atomic Absorption Spectrophotometer (AAS- UNICAM 919 model) [35]. These analyses were conducted at the Sokoine University of Agriculture, in the laboratory of the Department of Soil Science.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition of Gypsite

The data for the chemical composition of the gypsites are presented in Table 1. The results showed that all gypsite samples were not 100% pure gypsum, having 35.76, 56.76, 71.26 and 82.36% of $CaSO_4{\cdot}2H_2O$ for Itigi, Makanya, Msagali and Pindiro deposits, respectively compared to pure gypsum that contains 79% $CaSO_4$ and 21% $2H_2O$ with 18.6% S and 23.3% Ca [7]. Results also indicated that gypsites from Msagali and Pindiro contain high contents of S of 13.26% and 15.32%, respectively compared to Itigi and Makanya deposit with 6.65% and 10.52% S, respectively. Calcium contents of all gypsites were 7.6%, 9.5%, 4.8% and 11% for Makanya, Msagali, Itigi and Pindiro, respectively. This variation was probably due to the variation in the proportion of chemical elemental compositions of each deposit such as P, Mg, K, Na, Al, Si, Mn, As, Ni, Fe, Zn, Ba, Co and Cr. The compositions and concentrations of elements also depend on the chemistry of the host rock and environmental conditions, activating the weathering process [10]. Gypsum, calcium or magnesium carbonate, chlorides, other sulphate minerals, clay minerals or silica are considered as deleterious constituents of gypsites. As a result, in most mines, production of gypsum will have the purity ranging between 70% and 95%. This study indicates that gypsites in Tanzania are very inconsistent and the percentage of calcium sulphate varies even in the same deposit.

3.2 Loss on ignition

Loss on ignition implies the weight of gypsum after being heated. It indicates the prehydration or carbonation due to prolonged exposure to air, water and carbon dioxide. By heating gypsum up to 900°C, the water of crystallisation and carbonates were lost. In addition, LOI indicates the quality of analysed samples. Samples with high LOI indicates low quality compared gypsite with low LOI. Results indicated that gypsite sample from Itigi deposit had high LOI (24.45%) hence was considered to have low quality compared to gypsite from Pindiro with 21.05% LOI, which is of the good quality. The results of LOI from the gypsites followed an increasing trend of quality of Itigi (24.45) > Makanya (21.60) > Msagali (21.28) > Pindiro (21.05). These results are in conformity with the findings of Harris [27] who reported 85% purity of gypsum in Pindiro deposit. In addition, Abduel, [36] reported that Tanzania has the best gypsum deposits in the world in terms of percentage purity, situated in Pindiro and Mbane, and Kilwa in Lindi region.

3.3 Macronutrients Concentrations

Results of the concentrations of P, K_2O, CaO, $CaSO_4$, Na and Mg in the gypsite samples are shown in (Table 1). The amount of total P in all samples was in medium range with values ranging from 6.28 to 14.68 $mgkg^{-1}$ [37]. Caires, et al. [11] reported that gypsum contains P as an impurity, and it is important for plant nutrition.

Potassium oxide (K_2O) in Msagali deposit was (0.63%) while other deposits had K_2O < 0.01%. The amount of sodium was in the increasing trend of 32.07 < 35.30 < 43.55 < 50.61 mg/kg for Pindiro, Msagali, Makanya, and Itigi, respectively. Magnesium was high in all deposits whereas CaO and $CaSO_4$ were variable. However, Pindiro had high amounts of $CaSO_4$ followed by Msagali, Makanya and Itigi, respectively.

Table 1. The XRF analytical results of the gypsites samples

	Elemental composition														
	L.O.I	**SiO_2**	**K_2O**	**CaO**	**$CaSO_4.2H_2O$**	**Al**	**Cr**	**Fe**	**Mn**	**Co**	**P**	**Ni**	**Na**	**Ba**	**Mg**
Location	**(%)**					**mg kg^{-1}**									
Makanya	21.6	12.96	< 0.01	35.01	56.53	0.18	0.004	0.72	180.78	39.26	11.86	<0.01	43.55	11.11	2062
Msagali	21.28	6.45	0.63	33.17	71.26	0.19	0.008	0.59	120.18	37.61	8.13	<0.01	35.3	12.47	2355.4
Itigi	24.45	24.39	< 0.01	34.7	35.76	0.18	0.005	0.66	137.85	29.62	14.68	40.8	50.61	13.03	2118.6
Pindiro	21.05	0.88	< 0.01	35.88	82.36	0.08	0.002	0.16	105.78	25.84	6.28	<0.01	32.07	11.84	2339.3

Furthermore, results showed that the studied gypsites had siliceous minerals probably quartz (SiO_2) as impurities. The amounts of SiO_2 differed among the deposits but Pindiro had the lowest while Itigi recorded the highest SiO_2. Quartz does not contribute important plant nutrients in soils and thus is regarded as impurities in gypsites.

Results in (Table 2) showed that both deposits contain high amounts of Mg with concentration values of 2355.4 mg kg^{-1} and 2339.3 mg kg^{-1} for Msagali and Pindiro gypsites, respectively. However, only 0.69% and 0.73% equivalent to 16.28 and 17.19 mg kg^{-1} can be extracted by plants for metabolism. Extractable Ca was 101.97 and 116.05 mg kg^{-1} for Msagali and Pindiro gypsites, respectively. The gypsite from Pindiro deposit had more extractable Ca which makes the difference of 14.08 mg kg^{-1} more than that found in Msagali deposit.

Table 2. Extractable sulphur, calcium, magnesium and some PTEs (mg kg^{-1}) in gypsites from Pindiro and Msagali deposits

Element	Pindiro site	Msagali site
SO_4-S	750.79	501.97
Mg	17.19	16.28
Ca	116.05	101.97
Cu	1.09	0.95
Fe	<0.01	<0.01
Zn	0.05	0.14
Mn	0.62	0.62
Co	<0.01	<0.01
Cd	< 0.01	< 0.01
Cr	< 0.01	< 0.01
Pb	< 0.01	< 0.01
Ni	< 0.01	< 0.01

3.4 Micronutrients Concentrations

The XRF analytical results in Table 1 indicates that the micronutrients Fe was low in all gypsites while Mn was relatively medium compared to the amounts of these elements when present in soils [36]. This shows that gypsite can supply Mn for plants.

3.5 Elements of environmental concern

Heavy metals accumulation in soils is of major concern in agricultural production due to the adverse effects on food safety and marketability, crop growth due to phytotoxicity and environmental health of soil organisms. Metal toxicity has high impact and relevance to plants, and consequently, it affects the ecosystem, where the plants form an integral component. Table 2 shows that the amounts of extractable Ni, Cr, Co, Ba, and Al were in acceptable ranges. Dontsova, et al. [38] reported the elements of environmental concern when present in high levels might cause toxicity or may affect the availability and uptake of essential plant nutrients in soils. Nagajyotib, et al. [39] and Allaway [40] reported the range of heavy metals of typical uncontaminated soils as follows; Cd 0.01–0.7 mg kg^{-1}, Co 1– 40 mg kg^{-1} , Cr 5–3,000 mg kg^{-1}, Cu 2–100 mg kg^{-1}, Fe 7,000 –55,000 mg kg^{-1}, Mn 100 – 4,000 mg kg^{-1}, Mo 0.2–5 mg kg^{-1}, Ni 10 – 100 mg kg^{-1}, Pb 2–200 mg kg^{-1} and Zn 10 –300 mg kg^{-1}. Analysis of extractable fractions (Table 2) showed that none of the PTEs in gypsites could affect nutrients uptake by the plant when applied as an amendment or as fertiliser (as a source of S and Ca).

Extractable fractions of micronutrients Zn and Mn for gypsites from Msagali and Pindiro were relatively small. According to Tisdale, et al. [41], the amount of extractable Zn found in gypsites from Pindiro and Msagali deposits are categorised as low while Cu is categorised as high. The amount of extractable Cu is sufficient when applied in soils. A total amount of Mn in gypsites from Msagali and Pindiro (Table 1) were 120.18 and 105.78 mg kg^{-1}, respectively but only 0.62 mg kg^{-1} could be extractable for both deposits (Table 2). The extractable fractions were equivalent to 0.5% and 0.59% for Msagali and Pindiro, respectively. According to Tisdale, et al. [40], 0.62 mg Mn kg^{-1} of extractable fractions found in both deposits could be rated as low when present in soils.

Heavy metals are generally toxic to most plants for their metabolism and growth if their concentrations exceed some maximum permissible limits [42]. The extractable potentially toxic elements such as extractable Fe, Cd, Cr, Co and Ni found in the studied gypsites were all less than detectable limits and thus, use of these gypsites in soils could not have detrimental effects to plants. The total amount of Co found in these deposits were 37.61 and 25.84 mg kg^{-1} but not easily extracted by plants. This could be attributed to the Co being strongly held in exchangeable sites of minerals present in gypsites. Msaki and Banzi [43] reported that natural gypsum and gypsum derived products from Tanzania have traces of radioactivity. However, the associated levels are not detrimental to health.

4. CONCLUSION AND RECOMMENDATIONS

From the results of this study, the following conclusions were drawn.z

From the X-ray Fluorescence analysis, gypsite from different sources differ regarding their quality as plant nutrient source and as a soil amendment due to variations in their chemical composition. Sulphur contents of the gypsite followed the following trend respectively Pindiro (15.32%) > Msagali (13.26) > Makanya (10.52%) > Itigi (6.65%), and Calcium trend was Pindiro (11%) > Msagali (9.5%) > Makanya (7.6%) > Itigi (4.8%) and all the studied gypsite samples contains potentially toxic elements (Cd, Co, Cr, Cu, Fe, Mn, Ni and Zn), but the levels are not potentially toxic to plants and hence do not interfere with plant nutrient uptake.

We recommend the characterisation of gypsites from other deposits in the country is required to generate information on their quantity and suitability for use on soil amendment for the increased agricultural productivity of Tanzanian soils. Also, quantification of the good quality gypsite deposits is essential to ensure their long-term availability. Long-term effects of PTEs in gypsite when applied in different soils should be studied, and economic analysis on the benefits of using gypsites is essential before attracting investors to process and sell to farmers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Mkapa BW. Towards agriculture-led growth in Tanzania: Policies, priorities and strategies. The 10th Sokoine Memorial lecture by his excellency Benjamin William Mkapa, President of the United Republic of Tanzania, Sokoine University of Agriculture, Morogoro. The Government Printer, Dar es Salaam, Tanzania. 2005; 32.
2. Mmbaga TE, Lyamchai CY. Drought management options in maize production in Northern Tanzania. In Integrated approaches to higher maize productivity in the new millennium. Proceedings of the Seventh Eastern and Southern Africa Regional Maize Conference, Nairobi, Kenya, CIMMYT. 2002;2004;281.
3. Ley G, Baltissen G, Veldkamp W, Nyaki A, Schrader T. Towards integrated soil fertility management in Tanzania. Developing farmers' options and responsive policies in the context of prevailing agro-ecological, socio-economic and institutional conditions. Amsterdam. 2002;102.
4. Crocker W. History of the use of agricultural gypsum. Gypsum Industries Association, Chicago, IL; 1922.
5. Chen L, Dick WA. Gypsum as an agricultural amendment: General use guidelines. Ohio State University Extension; 2011.
6. Mandal PK, Mandal TK. Anion water in gypsum (CaSO4· 2H2O) and hemihydrate (CaSO4· 1/2H2O). Cement and Concrete Research. 2002;32(2):313-6.
7. Dontsova KM, Norton LD. Clay dispersion, infiltration, and erosion as influenced by exchangeable Ca and Mg. Soil Science. 2002;167(3):184-93.
8. Korcak RF. Fluidized bed material applied at disposal levels: Effects on an apple orchard. Journal of environmental quality. 1988;17(3):469-73.
9. Bolan NS, Syers JK, Sumner ME. Calcium-induced sulfate adsorption by soils. Soil Science Society of America Journal. 1993; 57(3):691-6.
10. Brady NC, Weil RR. The nature and properties of soils. 14th Ed. New Jersey: Pearson Prentice Hall; 2008.
11. Caires EF, Blum J, Barth G, Garbuio FJ, Kusman MT. Changes in chemical soil characteristics and soybean response to lime and gypsum applications in a no-tillage system. Revista Brasileira de Ciência do Solo. 2003;27(2):275-86.
12. Toma M, Sumner ME, Weeks G, Saigusa M. Long-term effects of gypsum on crop yield and subsoil chemical properties. Soil Science Society of America Journal. 1999; 63(4):891-5.

13. Ritchey KD, Snuffer JD. Limestone, gypsum, and magnesium oxide influence restoration of an abandoned Appalachian pasture. Agronomy Journal. 2002;94(4): 830-9.
14. Hue NV. Responses of coffee seedlings to calcium and zinc amendments to two Hawaiian acid soils. Journal of Plant Nutrition. 2004;27(2):261-74.
15. Sahin U, Oztas T, Anapali O. Effects of consecutive applications of gypsum in equal, increasing, and decreasing quantities on soil hydraulic conductivity of a saline-sodic soil. Journal of Plant Nutrition and Soil Science. 2003;166(5): 621-4.
16. Chen L, Ramsier C, Bigham J, Slater B, Kost D, Lee YB, Dick WA. Oxidation of FGD-CaSO3 and effect on soil chemical properties when applied to the soil surface. Fuel. 2009;88(7):1167-72.
17. Takahashi T, Ikeda Y, Nakamura H, Nanzyo M. Efficiency of gypsum application to acid Andosols estimated using aluminum release rates and plant root growth. Soil Science & Plant Nutrition. 2006;52(5):584-92.
18. Campbell CG, Garrido F, Illera V, García-González MT. Transport of Cd, Cu and Pb in an acid soil amended with phosphogypsum, sugar foam and phosphoric rock. Applied Geochemistry. 2006;21(6):1030-43.
19. Sumner ME. Soil chemical responses to FGD gypsum and their impact on crop yields. Paper presented at the Workshop on Agricultural and Industrial Uses of FGD Gypsum. 2007;65.
20. Sakal R, Singh AP. Sulphur in Balanced Fertilisation in Eastern India.(in). In Proc. The Suphur Institute (TSI)/Fertiliser Association of India (FAI)/International Fertiliser Industry Association (IFA) Symp. on Sulphur in Balanced Fertilisation 1997; 1-6.
21. Tandon HL. Sulphur research and agricultural production in India.
22. Pasricha NS, Fox RL. Plant nutrient sulfur in the tropics and subtropics. Advances in Agronomy (USA); 1993.
23. Murrell TS. Average nutrient removal rates for crops in the northcentral region. North America–North Central. International Plant Nutrition Institute; 2005.
24. Ahmad N, Saleem MT, Rashid M, Jalil A. Sulfur status and crop response in Pakistan soils. NNFDC Publication. 1994; 7(94).
25. Kisetu E, Teveli CN. Response of green gram (*Vigna radiata* L.) to an application of Minjingu Mazao fertilizer grown on Olasiti soils from Minjingu-Manyara, Tanzania. Pak J Biol Sci. 2013;16(22):1601-4.
26. Kimbi GG, Mnkeni PN. Effectiveness of partially acidulated and beneficiated Minjingu rock phosphate as sources of phosphorus for maize and sorghum in three acid soils of Tanzania. Norwegian Journal of Agricultural Sciences. 1996;10: 301-8.
27. Harris JF. Summary of the geology of Tanganyika, part IV, economic geology. Memoir of the Geological Survey of Tanganyika. 1959;4:1-43.
28. Adu-Gyamfi JJ, Myaka FA, Sakala WD, Odgaard R, Vesterager JM, Høgh-Jensen H. Biological nitrogen fixation and nitrogen and phosphorus budgets in farmer-managed intercrops of maize–pigeonpea in semi-arid southern and eastern Africa. Plant and Soil. 2007;295(1-2):127-36.
29. Nyasasi BT, Kisetu E. Determination of land productivity under maize-cowpea intercropping system in agro-ecological zone of Mount Uluguru in Morogoro, Tanzania. Global Science Research Journal. 2014;2(2):147-57.
30. Kwesiga F, Coe R. The effect of short rotation Sesbania sesban planted fallows on maize yield. Forest Ecology and Management. 1994;64(2-3):199-208.
31. Duarah I, Deka M, Saikia N, Boruah HD. Phosphate solubilizers enhance NPK fertilizer use efficiency in rice and legume cultivation. 3 Biotechology. 2011;1(4):227-38.
32. Mboera LEG, Kamugisha ML, Rumisha SF, Msangen HA, Barongo V, Malecela EK, Kisanga L, Maghondi F, Gwilla Y, Kitua AY, Molteni F. Malaria epidemiology studies in Mpwapwa District, Central Tanzania. Report submitted to the National Malaria Control Programme, Ministry of Health, Dar es salaam, Tanzania; 2001.
33. Khan SU, Webster GR. Determination of gypsum in solonetzic soils by an x-ray technique. Analyst. 1968; 93(1107):400-2.
34. Moberg JP. Soil analysis manual (revised edition). The Royal Veterinary and Agricultural University, Chemistry Department, Copenhagen, Denmark. 2001;137.

35. Lindsay WL, Norvell WA. Development of a DTPA soil test for zinc, iron, manganese, and copper 1. Soil Science Society of America Journal. 1978;42(3):421-8.
36. Abduel, E. Tanzania: Nation boasts of best gypsum deposits globally. Tanzania Daily News Dar es salaam; 2011. Available:http://allafrica.com/stories/201107260979.html
37. Landon JR. Booker tropical soil manual. A Handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman, NewYork. 1991;450.
38. Dontsova K, Lee YB, Slater BK, Bigham JM. Gypsum for agricultural use in Ohio: Sources and quality of available products. Ohio State University Extension Fact Sheet, ANR. 2005;20(5).
39. Nagajyoti PC, Lee KD, Sreekanth TV. Heavy metals, occurrence and toxicity for plants: A review. Environmental Chemistry Letters. 2010;8(3):199-216.
40. Allaway WH. Agronomic controls over the environmental cycling of trace elements. In Advances in agronomy. Academic Press. 1968;20:235-274.
41. Tisdale SL, Nelson, WL Beaton, JD Havlin, JL. Soil fertility and fertilizers 6th edition. Prentice Hall, New Jersey. 2003;634.
42. Melo MR, Flores NR, Murrieta SV, Tovar AR, Zúñiga AG, Hernández OF, Mendoza AP, Pérez NO, Dorantes AR. Comparative plant growth promoting traits and distribution of rhizobacteria associated with heavy metals in contaminated soils. International Journal of Environmental Science & Technology. 2011;8(4):807-16.
43. Msaki P, Banzi FP. Radioactivity in products derived from gypsum in Tanzania. Radiation Protection Dosimetry. 2000;91(4):409-12.

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