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Characterization of Vertisols Fertility Status and Their Implications on Chickpea (*Cicer arietinum L.*) Farming in Semi-Arid Areas of Itigi District in Tanzania

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Abstract. The study was conducted to assess biophysical and chemical properties of vertisols of Itigi District and examine their suitability for chickpea (Cicer arietinum L.) farming. Six soil composite samples were collected from top and subsoil of three selected farms used for growing chickpea and named as ITG-P1, ITG-P2 and ITG-P3. All profiles had a depth of 144 cm with heavy clay texture. pH levels varied from slight acidic to moderate alkaline, thus, favoring chickpea production. Exch. bases including Mg, K, and Na ranged from low to medium while Exch. Ca and CEC were high in all profiles, thereby, providing supportive environment for growth of chickpea. Available P was low and ranged from 0.54 to 2.10 mg/kg which was crucial for chickpea production necessitating fertilization with 30 to 80 kg of P2O5 /ha depending on the P available. The level of K varied as in ITG-P2 was adequate (>15 cmol(+)/kg) while in ITG-P1 and ITG-P3 was very low (<2 cmol(+)/kg) necessitating application of 30 kg of K2O/ha for chickpea production. Studied profiles had a slight difference in assessed characteristics, hence, the need to understand fertilizer demand for chickpea production was important. Understanding fertility status of soils is important before investing in crop production where such information is not known.

Keywords: chickpea, fertility status, Itigi, semi-arid, vertisols

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1. Introduction

Worldwide, vertisols are considered of high importance in agricultural use as in India, China and some parts of East Africa which have been very productive from the past to date [1]. Vertisols are classified as heavy textured soils owing to the high percentage of clay and observable biophysical properties which are natured with high water holding capacity and which develop deep cracks during dry seasons commonly in the semi-arid areas [2]. 30% of vertisols occur in Africa in the arid, semi-arid and humid climates where they contribute highly to food security and economies in several countries including Botswana, Ethiopia, Tanzania, Nigeria, Niger, Burkina Faso, Chad, Sudan, Somalia, Kenya, Burundi, Malawi, Zambia and Zimbabwe [3]. In Africa, Australia and

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America, the productivity of vertisols has been downgrading due to their in-tensive utilization and inadequate management. The declining of their fertility status which has been witnessed from time to time has been a result perennial erosion, extensive crop farming with poor agronomic practices and minimal use of fertilizers [4].

Chickpea, just like other agricultural produce, benefit farmers in meeting quality protein requirements and enhance the potentiality of the agricultural sector through its ecological significance through assimilation of soil nitrogen and reduction of the excessive use of mineral fertilizers [5]. Legumes including chickpea improve soil productivity when cereals are grown on the same field after their harvest [6]. Globally, the leading producers of chickpea include India, Burma, Yemen Spain, United States Russia, Pakistan, Iran, Argentina, Tanzania, Ethiopia, Turkey and Canada among others which account for more than half of the global chickpea production in the recent years [7]. Currently, the global average production of chickpea is 0.9 t/ha which is 5.1 t/ha far back from the minimal potential estimation production when the crop is farmed in favorable conditions whereby losses in chickpea yields in various agricultural regions is due to limited availability of field soil mineral nutrients [8]; [9]. Despite vertisols being regarded as productive when positively managed, some of their characteristics have critically resulted in low yields essentially on low input agriculture [10]. Studies conducted in other areas such as India and Ethiopia where chickpea is highly grown shows a crucial demand in understanding the vertisols properties in order to enable farmers to adopt appropriate farming practices for improved yields [1]. The common properties of vertisols are much known and documented; however, the limitation is that in certain areas their biophysical and chemical properties tend to differ due to certain unique environmental conditions [11].

Knowing the soil nutrient status and their variation of an area is crucial for sustainable agricultural development as soil has always been a potential non-renewable resource and core base for the agriculture industry [12]. The need to understand soil quality for agricultural development from decades back was inevitable due to the rising demand for various agricultural inputs and determining labor allocations as well as fiscal ones [13]. As a key factor in crop productivity, soil status directly affects crop yields when other factors are in optimum condition [14]. Soil and plant nutrients deter-mine the quality and quantity of yields [8]. In order to ensure that the agriculture sector becomes sustainable, the management of soil resources becomes indisputable for satisfactory agricultural production and meeting human needs [6]. Due to demographic changes including rapid population growth, rising demand for food and use of various friendly and unfriendly agronomic practices, loss of soil nutrients is tremendously increasing in most parts of the country, hence, lowering crop production which is currently experienced in several agro-ecological zones in Tanzania [15].

It is critically significant to make soil nutrient status assessment prior to chickpea farming so as to understand fertilizer requirements of the soils for the purpose of improving chickpea production in different areas in Tanzania [16]. This is because unbalanced fertility has accounted for a great loss in chickpea yields [17]. Regardless of their natural fertility, vertisols have certain properties that pose difficulties in agricultural production particularly when subjected to low agricultural input [1]. Understanding the available soil nutrients including soil pH, organic matter, available bases, texture as well biological activities is crucial in determining the type of crop suitable and enhancing its productivity [18]. In soils with deficiency of phosphorous (P), the production of chickpea performs poorly as it leads to nutrient less as pulse crops respond well where soil has sufficient P [17]. In most regions, vertisols are natured with low level of phosphorus caused to a large extent by fixation by calcareous properties [19]. Understanding the status of P in vertisols for chickpea performance is, therefore, vital and needs more attention [20].

Therefore, the primary aim of this study was to evaluate the biophysical and chemical properties of vertisols and the influence of available nutrients on chickpea production and recommend the level of fertilizer requirements for enhanced chickpea production in Itigi District and the country in general.

2. Methods

2.1. Description of the Study Area

The study was conducted in Itigi District of Singida Region where more than half of its farmland is covered by vertisols and among the commonly cultivated crop is chickpea [21]. The district is located on the southern hemisphere bearing coordinates 5° 42’ S and 34° 5’ E. Low rainfall and short rainy seasons natures the study site being a semi-arid area receiving rainfall annually ranging from 500 to 700 mm with a drought spell of one out of four years [22].

The altitude of the study site above the mean sea level ranges from 1,244 to 1,300 m and has different types of soils including sandy soils, greyish-brown sands and black cracking clay soil as well as reddish loamy sands with dark grey to black-clay soils [22]. Dominant vegetation in Itigi District include Itigi thickets, miombo and bushes [23]. Seasonal wetlands are found in some areas of the district which are located in the wetter vertisols traditionally known as Mbuga that are usually surrounded by sandy alluvial or slope washed ma-terials from near basement rocks [22], [24].

2.2. Data collection Procedures

A total of six soil composite samples were collected each from 15 units from three selected sites in Itigi District which were named as ITG-P1, ITG-P2 and ITG-P3. In each selected unit, observation was done for both topsoil and subsoil in accordance to FAO soil description guidelines [25]. Topsoil was considered due to its relevance for most performed activities by roots and fertilizers while subsoil was considered based on the nature of chickpea plant roots which are deeper and plant's ability in nitrogen fixation.

Observed physical characteristics were soil colour, textural class and depth while chemical parameters were soil pH, total Nitrogen (N), Organic Carbon (OC), organic matter (OM), exchangeable bases, electrical conductivity (EC), cation exchange capacity (CEC) and phosphorous (P) levels which were examined at the IITA Dar es Salaam Soil Laboratory. Standard lab procedures for handling and soil testing were used and involved air drying, grinding and sieving. Laboratory assessment (Table 1) was done using mid-infrared spectroscopy and wet chemistry through conventional methods. Soil pH and EC were determined by using potentiometric method while the textural class of the soil was categorized based on the USDA textural class triangle. The soil P, Ca, N, and K were determined through Atomic Emission Spectrometry. Total nitrogen was found with the use of Micro-Kjedahl digestion distillation and Walkley-Black method was used for organic carbon assessment.

Table1. Methods for Spoil Properties Analysis

Parameters	Method	Description
Soil pH	Potentiometric method	Soil: water 1:2
Soil EC	Potentiometric method	Soil: water 1:2
Soil P, Na, Ca, Mg, K	Atomic Emission Spectrometry	Ammonium acetate saturation
Total Nitrogen	Micro Kjedahl	Digestion distillation and titre
Textural class	USDA Textural triangle	USDA textural class triangle

3. Results and Discussion

3.1. Soil Physical Properties

Laboratory results for particle size distribution of sample soils are presented in Table 2. Presentation of these particle size distribution is based on depth of the profiles. Generally, all studied soils had high levels of clay than other particles sizes. The percentage of clay in profile ITG-P1 was 72% and 74% for topsoil and subsoil respectively. In profile ITG-P2, the clay percentage was 60% and 64% for topsoil and subsoil respectively. Topsoil in profile ITG-P3 had 58% clay underlying the subsoil with 54% clay. Silt percentages in all sites were generally low (<17%). Sand contents in all sites were as well low (<29%). The depth of the studied profiles varied from the three selected study fields. The profile depth for ITG-P1 was 144 cm while for ITG-P2 it was 120 cm and for ITG-03, 110 cm.

Table 2. Physical Characteristics of Vertisols in the Study Area

Profile	Location (Lat & Long)	Elevation AMSL (m)	Horizon	Depth (cm)	Particle size distribution (%)			Textural class
					Sand	Silt	Clay	
ITG-P1	5° 45' 22" S 34° 29' 5" E	1300	Ts	0-20	16	12	72	C
			Ss	20-40	15	11	74	C
ITG-P2	5° 41' 3" S 34° 30' 39" E	1310	Ts	0-20	27	13	60	C
			Ss	20-40	23	13	64	C
ITG-P3	5° 44' 51'' S 34° 28' 59" E	1290	Ts	0-20	27	15	58	C
			Ss	20-40	29	17	54	C

Note: Ts = Topsoil, Ss = subsoil, C = Clay, AMSL = Above Mean Sea Level, Lat = Latitude, Long = Longitude

3.2. Soil Chemical Properties

a. Soil pH

The soil pH (in H_2O) varied from one profile to another and among horizons of one profile (Table 3). The topsoil of study profiles had pH level of 7.55 in profile ITG-P1 while 6.65 in profile ITG-P2 and 6.37 in profile ITG-P3. The pH in subsoils were found to be 8.00 in profile ITG-P1, 7.78 in profile ITG-P3 and 6.83 in profile ITG-P3.

b. Organic Carbon (OC) and Organic Matter (OM)

The highest level of OC and OM were 1.59% and 2.73% respectively in topsoil of profile ITG-P3 while the lowest OC and OM levels were 1.01% and 1.74% in subsoil of profile ITG-P1. OC and OM decreased with increase in the depth from topsoil to subsoil in all the studied profiles.

c. Electrical Conductivity (EC)

The electrical conductivity varied among studied profiles. The EC of all studied were low (<1.7 ms/cm. The highest EC value was found in the subsoil of profile ITG-P3 to be 0.83 ms/cm while the lowest value was recorded in the topsoil of profile ITG-P2.

d. Total Nitrogen (TN)

Both topsoil and subsoil of profile ITG-P3 and topsoil of profile ITG-P1 had 0.08% of nitrogen while the topsoil of profile ITG-P2 was 0.06%. Nitrogen percentage in the subsoils of ITG-P1 and ITG-P2 were 0.07% and 0.05% respectively.

e. Available Phosphorus (Av. P)

Available P was 2.10 mg/kg, 0.61 mg/kg and 1.07 mg/kg in topsoils of profiles ITG-P1, ITG-P2 and ITG-P3 respectively. The subsoils of profiles ITG-P1, ITG-P2 and ITG-P3 had 1.18 mg/kg, 0.54 mg/kg and 0.89 mg/kg respectively.

f. Exchangeable Bases

Laboratory results for exchangeable bases is presented in Table 3. Exchangeable calcium (Exch. Ca) greatly varied between profile ITG-P1 and others which had 146.69 and 152.13 cmol(+)/kg for its topsoil and subsoil respectively. The topsoils of ITG-P2 and ITG-P3 had 19.43 and 19.75 cmol(+)/kg of Exch. Ca while their subsoil had 20.08 and 24.92 cmol(+)/kg respectively.

Exchangeable magnesium (Exch. Mg) was high in topsoil of profile ITG-P2 being 13.34 cmol(+)/kg with its subsoil value of 152.13 cmol(+)/kg. Topsoil Exch. Mg was found low in profile ITG-P1 with a value of 2.53 cmol(+)/kg while it was moderate in its subsoil that had a value of 9.24 cmol(+)/kg. Exch. Ca was very low in both topsoil and subsoil of profile ITIG-P3, their values being 0.36 and 0.35 cmol(+)/kg respectively.

The highest levels of exchangeable potassium were found in ITG-P2 that had 15.26 and 17.52 cmol(+)/kg for its topsoil and subsoil respectively. Also topsoil of profile ITG-P3 was rated high in terms of the present Exch. Ca with a value of 5.29 cmol(+)/kg while medium levels were found in topsoils of ITG-P1with a value of 1.15 cmol(+)/kg and subsoils of ITG-P1 (3.09 cmol(+)/kg) and profile ITG-P3 with a value of 0.56 cmol(+)/kg.

The highest value of Exch. Na was found in topsoil of profile ITG-P1 which had a val-ue of 0.85 cmol(+)/kg while the lowest value was found in subsoil of profile ITG-P2 with a value of 0.02 cmol(+)/kg.

g. Cation Exchange Capacity (CEC)

Topsoil CEC were 162.03, 37.58 and 25.46 cmol(+)/kg while for subsoil were 167.42, 47.15 and 25.85 cmol(+)/kg in profiles IPD-P1, DMR-P1 and ITG-P1 respectively. These study profiles had high levels of CEC due to more mixed clay mineralogy [26].

3.3. Fertility Status Suitability to Chickpea growth

The depth the studied profiles had minor variation with a range of 34 cm. The variation of the depth does not affect the growth of chickpea in any of these studied fields as they provide adequate depth for chickpea roots to grow well and perform other biological activities. Chickpea has a deep root system that enables it to tolerate drought [27] and fertilizer balance [28] which can grow to a depth of 120 cm.

Clay level in ITG-P1 and ITG-P2 increase with increase in depth from topsoil to sub-soil contrary to ITG-P3 though clay percentage dominated other particles and soils were clay based on USDA soil textural triangle. The textural class of all studied pro-files in both topsoil and subsoil was clay that made the soil to have high water holding capacity which is essential for chickpea growth that needs retained soil moisture for germination, growth and production as described by [29] which established that a high clay percentage in the soil influences its' high-water holding capacity of the soil.

The understanding of soil pH was crucial due to its influence on soil available nutrients, microbiological activities, various processes such as ammonification and nitrification as well the growth of plant roots [30]. The level of pH in observed profiles though increased significantly from topsoil to subsoil in all studied profiles and rated ranging from slight acidic to moderate alkaline as ratings by [31] provided favorable conditions for the growth and production of chickpea as the crop grows well in soils with pH that range from 6.0 to 8.0 as suggested by Gaur et al. (2010). Additionally, most crops perform well in soils with pH ranging from 6.5 to 7.5 and soils with pH>7.5 affects availability of certain nutrients including phosphorus, a challenge that would like to be experienced in Profile ITG-P1 [26].

The electrical conductivity of the soil was very low implying that the soil was less saline; hence, provided conducive conditions for plant growth. Electrical conductivity can affect crop growth and lead to low yields production when it exceeds 1.7 ms/cm [14]. However, chickpea particularly desi variety can tolerate and grow in saline soils with high electrical conductivity that range from 4 to 6ms/cm as found by [32].

Organic carbon is an essential indicator of soil organic matter in the respective soils. It influences various soil functions including biological, chemical and physical processes. The available level of organic carbon in all profiles was low as based on indices by [32] with minimal variation (Table 3) implying that there was a low level of organic matter in the soils despite their dark colour. The possible rea-sons for low level of OC and OM in semi-arid areas is due to limited availability of vegetation caused by low rainfall, hence, enhancing low level of accumulation and decomposition of plants [26]. Low level of organic matter has been adversely affecting yields production of various crops including chickpea [32]. Therefore, to meet the demanded level for proper crop growth, the use of farmyard manure (FYM) or composite manure in required quantity is important.

CEC in all sampled fields was very high for both topsoil and subsoil. The high level of CEC in the soil protects soluble cations against leaching process that affects the root zone and enhances soil capacity in resisting soil pH changes [33]. Therefore, the level of CEC in the studied profiles was sufficient for offering conducive grounds for chickpea production.

The level of Phosphorus in all profiles was low (<2.10 mg/kg) based on indices by [34] though increasing with an increase in depth from topsoil to subsoil. The low levels of available P might have been due to P fixation under acidity and alkalinity in forming insoluble compounds and presence of parent materials which are having low phosphorus content [26] in which the situation limits crop plants uptake of P. vertisols are characterized with low level of P as other studies have revealed the same findings including [18], [20] and [35]. Low level of P in soil reduces chick-pea yields [35]. Various studies have recommended the addition of phosphorus in the soil with the fertilizer in a range of 30 to 80 kg of P_2O_5 /ha depending on the available level and soil moisture [9]; [36]. Therefore, farms in these study areas required fertilization of P in appropriate amounts.

Table 3. Nutrient Levels in Vertisols of Selected Profiles in Itigi

Study area		Chemical parameters									
Profile	Depth (cm)	pH (H_2O)	EC (ms/cm)	OC (%)	OM (%)	P (mg/kg)	Exchangeable bases and CEC cmol (+)/kg				
							Ca	Mg	K	Na	CEC
IPD-P1	0-20	7.55	0.250	1.07	1.84	2.10	146.69	13.34	1.15	0.85	162.03
	20-40	8.00	0.200	1.01	1.74	1.18	152.13	11.37	3.09	0.83	167.42
DMR-P1	0-20	6.65	0.156	1.14	1.96	0.61	19.43	2.53	15.26	0.36	37.58
	20-40	7.78	0.235	1.22	2.10	0.54	20.08	9.24	17.52	0.31	47.15
ITG-P1	0-20	6.37	0.225	1.59	2.73	1.07	19.75	0.36	5.29	0.06	25.46
	20-40	6.84	0.829	1.31	2.25	0.89	24.92	0.35	0.56	0.02	25.85

Note: EC = Electrical conductivity, OC = organic carbon, OM = organic matter.

The level of nitrogen slightly varied among horizons of the sampled soil composites (Table 3). All studied composites had low level of nitrogen (<0.08%) based on de-scription by [32] which might be an outcome of the nature of the crop grown in these selected fields [6], [37]. The sample soils reflect the nature of the vertisols as in other studies including [20] described that vertisols are always natured with low level of nitrogen due to denitrification as an outcome of poor drainage. Chickpea which is a legume crop requires a little amount of N as the crop has the ability to stimulate atmospheric N with the little available N in the soil. Therefore, the attained level of N in the soil is adequate to stimulate nitrogen fixation by chickpea as an overdose N declines biological features and biochemical roles in the soil [28]. Additionally, chickpea among other legumes is used in developing countries where they fail to meet the expenses of fertilizer N to fix almost 11 million tons of N [38]-[39].

The level of Exch. Ca was high in all profiles and ranged from 24.92 to 152.13 cmol+/kg in which increased with an increase in depth. The level of Exch. Ca in all sample composites were very high based on indices by [40]. The findings of other studies showed that vertisols have higher level of Ca as the dominant cation in the ECE and always the added P in vertisols is transformed to calcium phosphate [20]. The high concentration of Ca in vertisols is due to their immobility as a result of limited leaching and most vertisols are found in areas with lime-stone. A study by [36] noted that adequate Ca and P are important for growth and production of chickpea; therefore, the attained level of Ca in all profiles provide adequate essential Ca for enhancing chickpea production. The level of Exch. Mg dominated the cations after Exch. Ca. which is common in vertisols [19] which was high in almost all horizons except in topsoil of ITG-P1 as rated by indices by [32]. Soils with a deficiency of Mg affects yield levels and quality of chickpea while adequate Mg enhances chickpea productivity [41]. The level of Exch. Mg in all profiles was adequate and could support chickpea production.

According to [40] the findings of the study indicates that Exch. K varied between very high and medium level. The present level of Exch. K in all profile horizons, except subsoil for profile ITG-P3, exceeded the desired amount of K for various crops to perform well though this posed no serious threat to crops. Most studies do not consider the role of K in chickpea growth though it can enhance a plant's ability to withstand various stresses including drought and excessive temperature [42]. For the sites with low level of K, various studies have shown that application of 30 kg of K_2O/ha has shown a potential enhancing chick-pea optimum growth, increased yields, improved quality and satisfactory net bene-fit [43]. Therefore, K fertilization in ITG-P1 and ITG-P3 is important for higher chickpea yields.

The attained level of Na was low in all profile (<0.85 cmol(+)/kg; hence, low Ex-changeable Sodium Percentage (ESP) (<0.52%) which means that the soils were not saline (Pierre et al., 2018). The low level of Exch. Na implies the soils are less sodic; therefore, pose no threat to the growth of plants and crops [14]. Chickpea grows well in soils with ESP <5%; therefore, it can grow well in study areas.

4. Conclusion

The level of P was inadequate in all profiles and K in ITG-P2 and ITG-P3. This necessitated the application of fertilizer that would boost the availability of such nutrients (P and K) to the soil for chickpea production based on required amount determined regarding the level of deficiency. This knowledge may provide a necessary understanding to most farmers, particularly in developing countries, who grow chickpea in vertisols with no application of fertilizers as most of them believe that dark colour of vertisols implicate fertility. Therefore, the study recommends application of fertilizer based on the soil nutrient status is essential for improving chickpea production.

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