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Review

Available iron distribution in Nigerian soils - A review

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Enhancement and maintenance of soil available iron (Fe) in a continuous cropping system such as practiced in Southeast Nigeria is critical to producing iron rich food crops and sustaining agricultural productivity. This review focused on the distribution of Fe in Nigerian soils and factors affecting its availability. It is understood that the amount of Fe in soils depends on soil texture, pH, calcium carbonate ($CaCO_3$) level, organic matter content, and other soil characteristics. However, soil organic matter and pH have the strongest influence on iron levels. Since both major factors could be enhanced through proper soil management, Fe availability for improved crop production could be achieved.

Key words: Soil management, organic matter, micronutrient, extractable iron.

INTRODUCTION

Efforts to reduce Fe and other micronutrient deficiencies among Nigerian populace have been directed towards breeding programmes aimed at producing micronutrients rich crop varieties. Recently a lot of donors are sponsoring research into the development of biofortified crop varieties. Commendable as these efforts are, their impact may not be far-reaching. Micronutrient fortified food may not get to women and children in remote villages and it will take some time for Fe-enriched crop varieties to be bred, multiplied, and distributed to the farmers.

Crops take up Fe from the soil. The level of Fe in the crop is a function of the type of crop and the amount of available Fe in the soil. There is a relationship between the level of Fe in the soil and the clay content of the soil, pH, and organic carbon (OC). Availability of most micronutrients is largely pH – dependent, availability decreases as pH increases (Marx et al., 1999).

Fe primarily originates from chemical weathering of the parent material. The majority of iron deposits are formed in sedimentary rock beds beneath the Earth's surface. Another source of iron-rich soil is magma flow from erupted volcanoes (Gao et al., 2008). Fe in soils exists in different forms and varies greatly in its availability to plants. Table 1 shows that the nature and the amount of various forms of Fe depend on soil texture, pH, calcium carbonate ($CaCO_3$) level, organic matter content, and other soil characteristics (Sharma et al., 2008; Kabata-Pendias and Pendias, 2001; Jiang et al., 2009). Soil organic matter and pH have the strongest influence on iron levels in soils. Iron levels decrease as pH increases and as organic matter decreases (Douglas, 2002).

Plants can uptake Fe in its ionic forms such as Fe^{2+} (ferrous form) and Fe^{3+} (ferric form). Fe^{3+} is insoluble at neutral and high pH, making iron unavailable to plants in alkaline and in calcareous soils. Most of the Fe in the earth crust is in the form of Fe^{3+}, though the Fe^{2+} form is physiologically more significant for plants (FertFacts,

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Table 1. Factors affecting the availability of Iron (Fe) in the soil.

Soil condition	Effects on Fe availability
Soil pH	High soil pH reduces Fe availability while low soil pH increases Fe availability. The high pH effect is increased in waterlogged, compacted, or other poorly aerated soils.
Low organic matter (OM)	In addition to being a source of Fe, OM compounds are able to form Fe complexes that improve availability.
Saturated, compacted, or other poorly aerated soils	In acid soils, this condition can increase Fe availability (to the point of toxicity).
High soil phosphorus (P)	Excessive amounts of soluble P, or high rates of P fertilizer, have been demonstrated to inhibit Fe uptake in many crops.
Form of N applied	Increased NO_3 -N uptake can reduce Fe uptake by causing an anion-cation imbalance in the plant.
Fe:Zn balance	Zn deficiency has been shown to increase the Fe uptake of many crops, sometimes to the point of toxicity. Conversely, high Zn availability reduces Fe uptake.
Fe:Mn balance	It is well documented that these two elements are antagonistic, and one will inhibit the uptake of the other.
K:Fe balance	K appears to play a very specific, but poorly understood role in the utilization of Fe. Some research indicates that low K availability can result in increased Fe uptake.
Fe:Mo (molybdenum) balance	High levels of available Mo can reduce the uptake of Fe by causing the precipitation of iron molybdate on the root surfaces. This is especially important in alkaline soils where the high pH reduces the availability of Fe while increasing that of Mo.
HCO-	Iron deficiency can be induced by the presence of the bicarbonate ion in the soil (saline and alkali conditions).

Adapted from Spectrum Analytic Inc (2013): Iron Basics.

2003). Fe is critical for chlorophyll formation and photosynthesis. Fe plays a role in energy transfer within the plant and it is a constituent of certain enzymes and proteins. Also, it is involved in nitrogen fixation (Spectrum Analytic, 2013). Appropriate soil management technology that will ensure adequate availability of Fe will depend on the knowledge of Fe status in the soils. This article reviews the distribution of Fe in soil fractions in Nigeria and factors affecting its availability.

SOILS IN NIGERIA AND FE CONTENT: A REVIEW

Iron (Fe) is considered adequate for plant growth when the available Fe concentration is more than 4.5 mg kg-^{1} (Agbenin, 2003; Ibrahim et al., 2011). Aghimien and Osenwota (2010) investigated the profile distribution of total and extractible Fe in the hydromorphic soils of Southern Nigeria. Total Fe ranged from 0.20 to 8.45% with means of 2.33%. The diethylenetriaminepentaacetic acid (DTPA)-extractable Fe ranged from 5.00 to 66.40 mg kg^{-1} with means of 36.48 mg kg^{-1}. Soils formed on basement complex were observed to be highest in total Fe as compared to soils formed on coastal plain sands and other parents materials.

Oyinlola and Chude (2010) conducted a study in Northern Guinea and Sudan savanna areas of Nigeria. The dominant parent material is Pre-Cambrian older granite (Alfisols) for both study areas. The soils were moderately acidic, the pH in water ranged from 4.6 to 6.8 with a mean of 5.5. The soils were rich in available Fe content which varied from 2.5 to 75 mg kg^{-1} with a mean of 19.6 mg kg^{-1}. High levels of available Fe in these soils were attributed to the acid conditions of the soils (Oyinlola and Chude, 2010).

Agbenin (2003) studied the sizes and changes in Fe fractions in a Northern Guinea Savanna Alfisol. The field was cultivated for 50 years and was fertilized with NPK, farmyard manure (FYM), and FYM and NPK. A natural site adjacent to the experimental field was also included. The distribution of Total Fe followed the distribution of clay in the soil profile across the field. The concentrations of DTPA extractable Fe were much higher than the critical levels delineated for soils. The recorded values of extractable Fe in the surface layer of soils with NPK, FYM, and FYM+ NPK were 61.4, 54.9, and 117.0 mg kg^{-1} respectively. Findings in this study show that there is no imminent Fe deficiency in the Savanna Alfisols even when the soil is under long-term cultivation as the soils seem to be adequately buffered with respect to Fe.

Shittu et al. (2010) studied the soil profile distribution of iron (Fe) in six locations in Ekiti State where charnockite (granitic) parent rocks occur. The study revealed that the Ap horizon contained the highest total Fe. DTPA extractable Fe was 26.70, 17.70, 18.80, 2.48, 26.70, and 6.90 mg kg^{-1} at Ado, Ikere, Ijan, Osin-Itapa, Ijesa-Isu and Ire, respectively. DTPA-extractable Fe decreased with depth, rather sharply, and so appears to be largely associated with organic matter content in the soils.

Lekwa and Whiteside (1986) evaluated the distribution

Table 2. Zinc, Cu, Fe, Mn, and particle size status of NRCRI farm soil.

Micronutrient	**(mg kg^{-1})**
Zn	4.7
Cu	0.8
Mn	7.7
Fe	210
Particle Size	**(%)**
Sand	73.8
Silt	6.2
Clay	20

Table 3. Mean values of available/extractible Fe in Nigerian soils.

Location	**Available Fe**	
	Mean	**Source**
Northern Guinea Savanna	19.6 mg kg^{-1}	Oyinlola and Chude, 2010
Northern Sudan Savanna	19.6 mg kg^{-1}	Oyinlola and Chude, 2010
Northern Guinea (NPK)	61.4 mg kg^{-1}	Agbenin, 2003
Northern Guinea (FYM)	54.9 mg kg^{-1}	Agbenin, 2003
Northern Guinea (NPK+FYM)	117.0 mg kg^{-1}	Agbenin, 2003
Southern hydromorphic soils	36.48 mg kg^{-1}	Aghimien and Osemwota, 2010
SW alluvial BCR	745.82 mg kg^{-1}	Elias and Gbadegesin, 2012
SW alluvial sedimentary rock parent material	678.30 mg kg^{-1}	Elias and Gbadegesin, 2012
Southwest charnockite (granitic) parent material	26.70 mg kg^{-1}	Shittu et al., 2010
Southeast coastal plain sand parent material	210.5 mg kg^{-1}	Adiele et al. (unpublished)

NPK –Nitrogen, phosphorus, and potassium fertilizer, FYM – Farmyard manure, SW – Southwest, and BCR - Basement Complex Rock parent material.

of citrate dithionite and ammonium-oxalate extractable Fe_2O_3 in nine soil profiles representative of soils in the Coastal Plain Sands geologic formation of Eastern Nigeria. The study areas were: Amakama, Asa Umunka, Akwete, Umuojima Owerrinta, Port Harcourt, and Eteo. Total Fe content generally increased with depth in the soils studied while extractible Fe decreased with depth. The decreases in the extractible Fe ratios with depth indicated that higher proportions of Fe were present in more crystalline forms in the lower horizons of the profiles.

Ibrahim et al. (2011) assessed the micronutrient status of soils of Billiri in Gombe State at 55 different locations. The soils' parent materials were derived from the older cretaceous sand stones (Bima sandstones and Yolde formation) and the crystalline basement complex rocks. The DTPA extractable Fe ranged from 10.31 to 20.17 mg kg^{-1}. Another study was conducted on the status and distribution of extractable micronutrients in Haplustults in Yamaltu-Deba Gombe by Mustapha et al. (2010). Results showed that extractable Fe ranged from 18.40 to 21.91 mg kg^{-1} (mean = 19.96 mg kg^{-1}). Furthermore, Mustapha et al. (2011) recorded 10.80 mg kg^{-1} (mean) available Fe in the Haplic usterts soils at Akko, Gombe.

Elias and Gbadegesin (2012) examined soil properties of two parent rock formations; basement complex and sedimentary rock formations in two ecological zones, at Oyan and Mokoloki, located in Southwestern (SW) Nigeria. The 0.1 N HCl available/extractible Fe in soils were 745.82 and 523.05 mg kg-^{1}, and 678.30 and 744.96 mg kg^{-1} for topsoil and subsoil on basement complex rock and sedimentary rock, respectively.

A study was carried out to determine the available Fe in ten soil samples obtained from the National Root Crops Research Institute (NRCRI) research farm, Umudike Abia State, Nigeria. The soils originated from coastal plain sands of the southeastern Nigeria with a value of pH 4.5. The available Fe ranged from 176.29 to 248.22 mg kg^{-1} which depicts Fe rich soil. Table 2 shows the chemical and physical properties of the soils evaluated. By comparing the extractable Fe contents in the soils reviewed (Table 3) with the established level set by Ibrahim et al. (2011), all the soils were found to be high in extractable Fe contents.

CONCLUSION

The knowledge of amount and distribution of Fe in soils in Nigeria is important for the proper understanding and management of the soil resources in order to enhance crop production in the era of intensive agricultural practice and climate change. From the literature survey carried out in this study, it appears that the sampled soils are adequately endowed with Fe. However, observation revealed that crops harvested from these soils do not have substantial levels of Fe. Fe malnutrition is associated with increased vulnerability to infection, impaired growth, anorexia, and impaired cognitive function. Research should focus on producing a comprehensive soil map, depicting amount of Fe and other micronutrients in all the agricultural regions. And develop soil management technologies that will enhance crop uptake of Fe. This will be a rightful step towards combating Fe malnutrition in Nigeria.

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Conflict of Interest

The authors have not declared any conflict of interest.

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