ANALYSIS OF IRON IONS CONCENTRATION IN IMPROVED TRADITIONAL IRRIGATION SYSTEMS: THE CASE OF RUANDA MAJENJE IRRIGATION SCHEME

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Abstract : an assessment on iron ions concentration in Ruanda Majenje Improved Traditional Irrigation System was done in order to comprehend its accumulation, distribution and establish appropriate remedial measures for sustainable crop production. Specifically the study identified physical indicators associated with iron toxicity and assessed water constituents in irrigation canals. Crops grown in the field, the soil and water in the canals were examined for visible symptoms of iron ions toxicity. Data were collected using standard forms and analysed using Microsoft Excel program. Key findings indicate 55% of the rice plants had tiny brown spots (bronzing) and some had uniform brown color. The water in the diversion point, main conveyance system and drainage system had zero to relatively low mean Fe^{2+} constituent concentration (0 - 0.22mg/l). On the contrary the mean iron constitute in the secondary canal was high >3.30Mg/L. Moreover, the mean water pH was 6.8 with a highest value of 7.0 found in the drainage system. It was concluded that despite Fe^{2+} being a trace nutrient element for crop productivity, Ruanda Majenje Irrigation scheme has symptoms of Fe^{2+} toxicity. Also, that the mean pH for optimum crop productivity was slightly low (<7) but suitable for most crops (6.5 – 7). There is a need to explore possibilities of promoting water and soil quality for among others sustainable crop production in Ruanda Majenje Improved Traditional Irrigation Scheme. More research is needed to investigate other water constituents including Cl, SO_4, Mn and $CaCo_3$

I. INTRODUCTION

According to Schulte (2004), Iron (Fe) is the fourth most-abundant element on earth, mostly in the form of ferro-magnesium silicates. In water iron is present mainly into two forms it can be either by soluble (Ferrous iron) or insoluble (Ferric iron). Water containing Ferrous iron is clear and colorless because the iron is completely dissolved in water, but when exposed to air or atmosphere the water turns cloudy and a reddish brown substance begins to form this sediment is the oxidized form of iron (Ferric iron) that will not dissolve in water.

In plants iron is considered as a micro-nutrient because only small amounts are required for normal plant growth. It plays an important role in respiration and photosynthesis simply because it is involved in chlorophyll synthesis and is essential for the function and maintenance of chloroplast structure (Acland,1977). Although iron is required for proper plant growth, plants need a certain amount of iron to survive. Exposure to too much iron can cause just as many problems as it's absence. Plants suffer iron deficiency with the symptoms of chlorosis and stunted growth. Excessive iron has a toxic effect on the plant weakening and eventually killing the plant, as the iron level continues to rise the plant ability to draw in other nutrient from the soil will also be hindered this means that the plant can no longer draw in essential substance from the soil.

Iron is a chemical element with symbol Fe from Latin word is known as (Ferrum). Iron occurs naturally in groundwater and surface water and its atomic number is 26.Like many elements, iron can exist in more than one chemical form (oxidation state) although the two most common forms of iron are Fe^{2+} (Ferrous) and Fe^{3+} (Ferric). In Fe^{2+} iron ion shares two of it's electrons and in Fe^{3+} iron ion shares three electrons (Schulte, 2004; WEI *et al*, 2010). In water, iron may be present as Fe^{2+}, which can be oxidized to Fe^{3+}(Katz,2009). According to Schulte (2004), Iron (Fe) is the fourth most-abundant element on earth, mostly in the form of ferro-magnesium silicates. Soils typically contain 1–5% total iron, or 20,000–100,000 lb/a in the plow layer. Most of the iron in soil is found in silicate minerals or iron oxides and hydroxides, forms that are not readily available for plant use. The iron oxides and hydroxides in soil are responsible for its reddish and yellowish colors. The red soils of eastern Wisconsin owe their color to iron oxide or hydroxide coatings on soil clay minerals. Iron is also indirectly responsible for much of the green color of growing plants, because of its role in the production of chlorophyll.

Research shows that several studies have been done at Ruanda Majenje Irrigation scheme but none has assessed micronutrients concentration in water which is conveyed, distributed and drained from the irrigation fields. While most of the Engineers and irrigation technicians identify improved infrastructures as key investments for better crop productivity, Farmers and extension workers in the Usangu Plains identify both improved infrastructure and management of macro nutrients as most important assistance for enhanced crop productivity. Moreover, since establishment of Ruanda Majenje improved traditional irrigation scheme, in 2002, farmers have been complaining of decreased and dormant crop productivity (Paddy) ranging from an average of 1.9 tones/hectare before the year 2004 to 3.8 tones/ha between 2005 – 2010 and 3.5 tones/ha from 2011 – 2016.

The main objective was to analyse iron ions concentration in water at Ruanda Majenje improved traditional Irrigation scheme in order to comprehend its accumulation, distribution and establish appropriate remedial measures for sustainable crop production.

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II. RESEARCH METHODOLOGY

Area of Study

The study was conducted in Ruanda-Majenje irrigation scheme in Middle Mkoji sub-Catchment in Mbarali District in Mbeya Region (Fig. 2). Mkoji Su-catchment is drained by the Mkoji River and is located in the Southwest of Tanzania, between latitude 7048’ and 9025’ South, and longitudes 33040’ and 34009’ East (SWMRG, 2004). This zone is in the transitions between the highlands and the flat plains of Usangu. This zone is located at an average altitude of 1100 m above sea level. It has mean annual rainfall of about 800 ranging between 700 and 1100 mm (SMUWC, 2000). The rainy season normally commences between the third or fourth decade of November and April. The zone is characterized by perennial and seasonal streams and rivers, which run from the Poroto Mountains. The presence of perennial water flows in the zone has led to a proliferation of irrigation schemes in this area. The schemes are both traditional and improved traditional irrigation systems.

Ruanda-Majenje irrigation scheme which is the biggest area under irrigation in the village covers an area of 371 ha with a total of 240 farmers. The scheme is subdivided into two areas. The upper part with light soils is used for crops such as maize, cassava, beans, and vegetables; to mention a few, while the lower part an area with heavy soils is used for paddy production. The scheme gets water from Lwanyo River. The river originates from Poroto mountain ranges and discharges its water into Great Ruaha River.

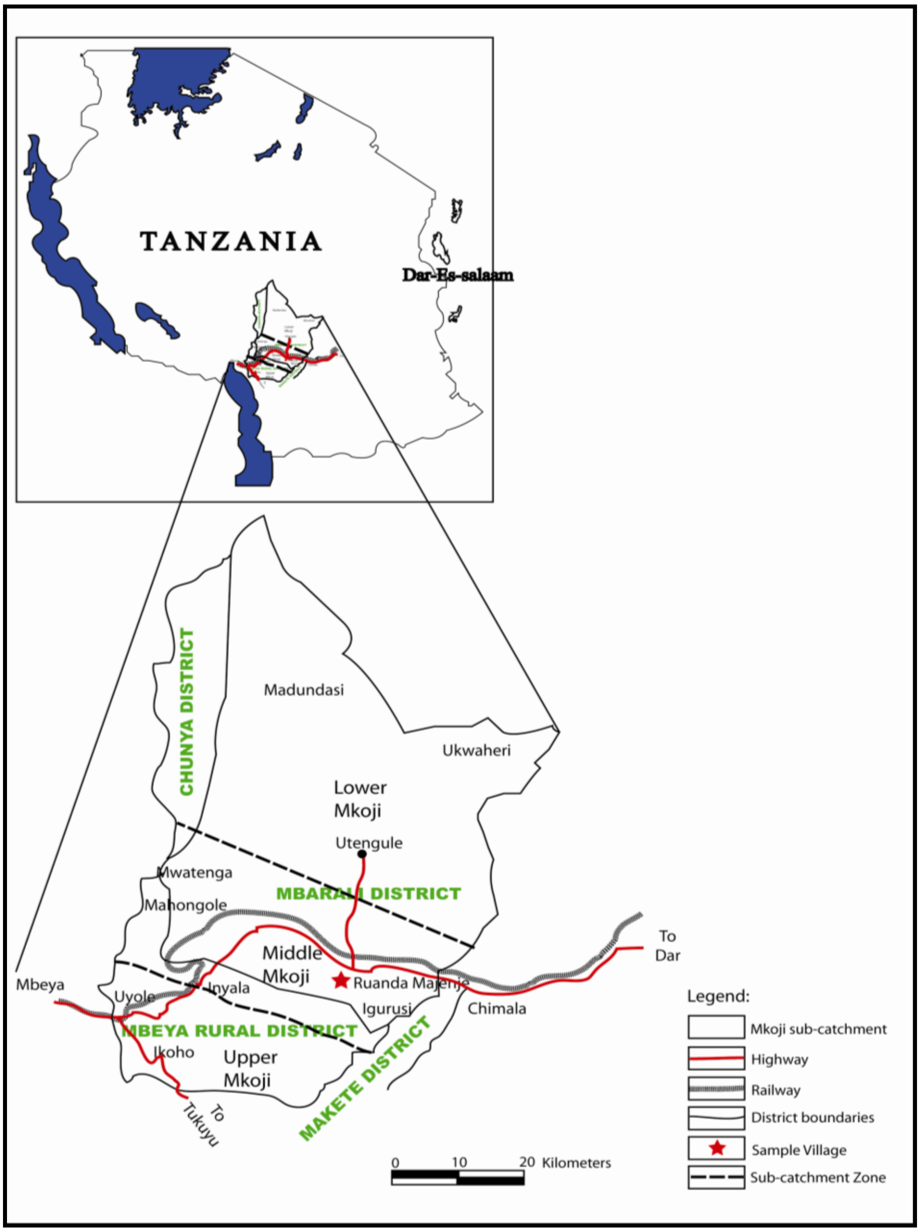

Figure 1: A map of Mkoji sub-Catchment showing the study area
Source: SWMRG (2004)

Research design

An experimental research design was used preceded by physical observation of visible symptoms associated with iron toxicity in the soil, on vegetation and in stagnant water. Physical characteristics that were observed included soil and water colour, Leaf colouration (leaf spots) and stunting.

Sampling procedures

Toxicity identification tests were done in the field and in the laboratory. This was performed in three stages; Step I: The general soil characteristics which included soil texture and soil colour were investigated in the fields and irrigation canals using Munsell colour system. Through this system colour space specified colours based on three colour dimensions: hue, value (lightness), and chroma (colour purity). This enabled specification by examining three numbers for three numbers for hue, value, and chroma in that order. Step II: Plant samples were taken using a ring population technique in which rings were tossed randomly throughout the irrigated fields and 6–10 samples of plant leaves were examined for colouration and spots. The results were correlated with standard symptoms for iron toxicity. Step III: Laboratory toxicity testing through a set of independent samples to confirm results from field tests.

Sampling unit and sample size

The sampling unit for the study was taken from the irrigated fields and irrigation canals; Water extractions and Soil samples. These were randomly selected in the fields and canals. The units were divided into blocks according to the secondary canals of the irrigated fields. Moreover the samples of plants with symptoms of toxicity were taken from the fields randomly using ring population technique.

Data Analysis

A number of close operations were used to analyse and summarize data collected which were then organized to draw the results and conclusions. Data collected from physical counts, soil separates, soil textural triangle, Munsell colour charts, pH meter analysis and toxicity testing (Fe2+ concentration) using a SMART 3 Calorimeter were correlated with standard values to draw inference.

III. RESULTS AND DISCUSSION

Physical indicators associated with iron toxicity
Leaf spots and Leaf coloration

Rice ring technique was used to determine population of rice plants with symptoms of iron toxicity (Leaf spots, and coloration). Results in Figure 1 show the highest physical count of plants with symptoms of iron toxicity is 121 plants (Block 5 Basin 5). On the contrary the lowest mean count of plants with symptoms of iron toxicity is 24 (Block 1 Basin 5). The third basin of block 4 – 5, and fourth and fifth basin of block 3 – 5, the number of plants with symptoms of irons ion toxicity is high. Moreover field visit envisaged that the areas were water logged a condition that might influence increased Fe2+ concentration. These results are supported by Dobermann and Fairhurst (2000) and Sahu and Mitra (1992), who argued that Fe2+ toxicity can occur when Zinc is deficient, or the soil is in a "reduced" condition caused by very wet or flooded conditions. Excess iron can result in Dark green foliage, stunted growth of tops and roots, dark brown to purple leaves on some plants (e.g. bronzing disease of rice).

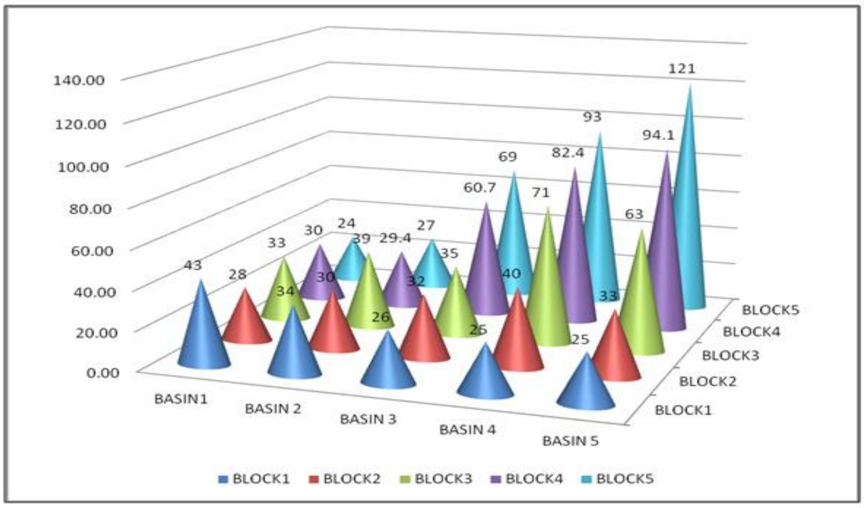

Figure 1: Distribution of Iron ions toxicity in the basins of each block

Soil colour

Results in Table 1 show that the soil colour in Ruanda Majenje Irrigation scheme, as determined by Munsell Colour Charts in the rice fields, are generally Light Gray to Brownish Gray with some portions which are Grayish Yellow and Olive Black. According to Moody and Cong (2008), Red, yellow, grey and bluish-grey colours result from iron in various forms. Under average conditions of air and moisture, iron forms a yellow oxide imparting a yellow colour to the soil. Where soils are well draining or under dry conditions, iron forms red oxides imparting a red colour to the soil. Yet in waterlogged soil, with a lack of air, iron forms in a reduced state giving the soil grey/green/bluish-grey colours.

Table 1: Results for soil colour test using Munsell colour system

Soil Sample	SOIL COLOUR	
	DRY SOIL	**MOIST SOIL**
Block No. 1	10YR 8/1 (Light Gray)	10YR 3/3 (Dark Brown)
Block L - Chuo	7.5YR 8/2 (Light Gray)	10YR 3/2 (Brownish Black)
Block No. 2	2.5YR 8/1(Light Gray)	2.5YR 4/2 (Dark Greyish Yellow)
Block No. 3	5YR 7/1 (Light Brownish Gray)	2.5YR 2/2 (Olive Black)

Source: Project Field Work (2017)

Soil Texture

Table 2 shows Ruanda Majenje soils comprise Sand fractions ranging from 25.4 – 28.8%, Silt 21.4 – 49.3% and Clay 25.4 – 29.8%. On average the soil fractions are 41.3% Clay, 31.5% Silt and 27.2% Clay and the soil textural class is Clay Loam; According to USDA Soil Textural Triangle (SSDS,1993). These results imply the soil textural class to comprise fine to medium texture. The portions with more fine texture could be the cause of smaller pore sizes and hence a lower infiltration rate. This could contribute to more reduction processes hence the possible cause of increased Fe2+ and FeOOH in water. The textural characteristics of the soil decide the oxidation reduction systems in the soil (Patra and Mohanity, 1994), they argued that the coarser the texture the more the oxidation and the finer the texture the more the reduction process. Also the authors reported that the high content soil with Light texture was due to the oxidation of ferrous iron to ferric iron and exchangeable Fe contest was lowest in light textured soil due to hydrolysis of Fe and Fe $(OH)_3$. Generally Clay contest of Fe toxic soils grouped under Utisols and Oxisols is normally high, while the Fe toxic inceptisol have low clay content.

Table 2: Results of soil textural class

BLOCK	MEASURED DEPTH (cm)				MEASURED DEPTH (%)			SOIL TEXTURAL CLASS
	S	Si	C	TOTAL	S	Si	C	
Block 1	1.8	3.5	1.8	7.1	25.4	49.3	25.4	Clay Loam
Block 2	4.0	2.7	2.3	9.0	44.4	30.0	25.6	Clay Loam
Block 3	3.5	1.9	2.1	7.5	46.7	25.3	28.0	Clay Loam
Block 4	4.1	1.8	2.5	8.4	48.8	21.4	29.8	Clay Loam
MEAN	3.4	2.5	2.2	8.0	41.3	31.5	27.2	Clay Loam

Source: Project Field Work (2017)

Water Constituents in Irrigation Canals

Water taken from the conveyance systems in the irrigation scheme was taken to the laboratory and analysed for two parameters, which are water pH level and iron (Fe) concentration. The results in Table 3 show that have a water pH is between 7.02 and 7.28 with a mean pH of 7.17. This pH is slightly alkaline i.e. > 7, however water suitable for irrigation should have a pH of 5.8 – 8 (Dobermann and Fairhurst, 2000). According to these results the pH of water is within the range required for optimum water quality therefore it is possible that the water supports optimum crop productivity thus does not contribute to increased iron ions toxicity in the irrigation scheme.

Results in Table 2 also show that iron constituent is between 0.17 to > 3.3 mg/L. The range of up to 0.3 mg/L is optimal limit for irrigation (Rowe and Abdel-Magid, 1995). These results explain that the water extracted from the main canal and secondary canal 1 and drainage canal have iron ions with the required limits for optimum crop productivity, while secondary canal 2 and 3 show high levels of iron ions concentration (Appendix 4 – Plate 1). Moreover, Rowe and Abdel-Magid (1995) observed that iron ions concentration limits above 5mg/L cause severe problems to crops. Therefore since secondary canal 2 and 3 show iron ions concentration is > 3.3 mg/L there are chances that the limits might exceed 5mg/L. These results explain that the irrigated rice fields in block 2 and 3, might have high iron toxicity.

Table 3. Water pH level and Iron ions concentration

SAMPLE EXTRACTION POINTS	PARAMETERS	
	WATER pH	IRON CONCENTRATION(mg/L)
Main Canal (US)	7.26	0.17
Secondary Canal 1	7.02	0.22
Secondary Canal 2	7.03	Limit >3.30
Secondary Canal 3	7.26	Limit >3.30
Drainage Canal	7.28	0.17
MEAN	7.17	

IV. SUMMARY

Iron toxicity is a syndrome of disorder associated with large concentrations of reduced iron (Fe2+) in the soil solution. The appearance of iron toxicity symptoms in rice involves an excessive uptake of Fe2+ by plant roots and its acropetal translocation into the leaves where an elevated production of toxic oxygen radicals can damage cell structural components and impair physiological processes. The typical visual symptom associated with these processes is the “bronzing” of the rice leaves and substantial associated yield losses. Visible symptoms of iron ions concentration in the soil and plants provide a clue to the irons concentration.

The study has shown all sampled rice plants have visible symptoms of iron ions toxicity (bronzing), whereby the highest mean is 66.91% and lowest is 30.86%. Field visit envisaged water logged areas. Soil texture (Clay) and soil colour (Grey and Yellow) which indicated a high possibility of inadequate air favouring iron reduction. Water pH is between 7.02 and 7.28 with a mean pH of 7.17. This pH is slightly alkaline i.e. > 7, however the water is suitable for irrigation since this pH is within recommended ranges (pH 5.8 – 8). Moreover results also show that iron constituent in water is between 0.17 to > 3.3 mg/L. Water in secondary canal 2 and 3 show high levels of iron ions concentration (>3.3mg/L) whereby limits above 5mg/L can cause severe problems to crops. A range of agronomic management interventions ought to be advocated to reduce the Fe2+ concentration in the soil or to foster the rice plants ability to cope with excess iron in either soil or the plant.

Conclusion

Findings from this study have analyzed two important water constituents (Fe2+ and pH) of water flows in conveyance systems of Ruanda Majenje Irrigation scheme. Moreover for the purpose of rice production the study also analysed two important physical properties which are soil texture that influences rate of iron ions oxidation and reduction processes and soil colour which gives a picture of the mineralogical composition of soil.

From this study both the analysed chemical and physical properties of canal flows, plants and soil have shown evidence of iron toxicity. Results have shown Iron ions level of up to more than 3.3mg/L, slightly high pH of up to 7.28. The results have also shown that the soils of Ruanda Majenje are generally light grayish and yellowish and the plants have bronzing symptoms with low crop productivity of 3.5tones/ha.

Recommendation

To conclude Fe toxicity can affect the rice crop throughout its growth cycle. Therefore there is a need to take measures that will enable sustainable use of Ruanda Majenje Irrigation scheme: important measures include the following:

i.) To prevent iron toxicity in areas where there are either less symptoms of toxicity or the water shows low concentration of irons ions in water (< 3.3 mg/L). by doing the following:

- Plant tolerant varieties or diversify crop production by introducing crops that withstand iron toxicity.
- Coat seeds with oxidants (e.g., Ca peroxide at 50−100% of seed weight)
- Delay planting until the peak in Fe2+ concentration has passed (i.e., not less than 10−20 d after flooding)
- Use intermittent irrigation and avoid continuous flooding on poorly drained soils containing a large concentration of Fe2+ and organic matter.
- Carry out dry tillage after the rice harvest to enhance Fe2+ oxidation during the fallow period, but this will require machinery (tractor)

ii.) To control iron toxicity in areas with iron concentration > 3.3 mg/L:

- Balance the use of fertilizers (NPK or NPK + lime).
- Apply sufficient Potassium (K) fertilizer.
- Avoid application of organic matter in the blocks where drainage is poor.
- Use urea (less acidifying) instead of ammonium sulfate (more acidifying)

Since there is currently no practical field management option to treat iron toxicity, areas with mild toxicity need be protected. Further research on other micronutrient levels in both water and the soil in Ruanda Majenje Irrigation scheme is important.

V. Acknowledgment

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