

The status of microelements in the selected ERPP irrigation schemes in Unguja and Pemba Islands, Zanzibar

Comment [H1]: Assessment should be added to the title as well as the name of country.

ABSTRACT

Aims: To investigate the status of microelements in the selected expanding rice production project irrigation schemes in Unguja and Pemba Islands, Zanzibar

Study design: Standard grid soil survey

Place and Duration of Study: Unguja and Pemba Isles Zanzibar during October and December, 2017.

Methodology: Detailed soil survey was conducted using pedogeomorphic approach and composite soil samples were collected at a depth of 0 – 30 cm for microelements investigation from each of the delineated mapping units.

Results: Results showed that the status of micronutrients (Fe, Zn and Mn) in the selected irrigation schemes varied ($P \leq 0.05$) with schemes and their respective mapping units, although in some cases, variations were not ($P \leq 0.05$) significant. In Unguja and Pemba irrigation schemes, there were generally moderate or optimum DTPA - extractable Fe, low DTPA - extractable Zn and high DTPA - extractable Mn levels. The data suggests that except for DTPA - extractable Zn which was low in all irrigation schemes, Fe and Mn were not limiting to crop growth and development. However, in Kwalempona (KWA-MP1: Hi1) and Machigini (MA-MP1: Hi1) irrigation schemes, Fe levels were rated as low or below critical limits. Additionally, the overall soil reaction in these irrigation schemes ranged from neutral (N) to very strongly acid (VSA).

Conclusion: In all, these results suggest that in order to improve crop production in the selected irrigation schemes, low Zn availability should be addressed by including it into fertilizer programs as well as proper soil pH management by reducing acidity through liming in the higher elevations and addition of organic matter (OM) in the plain or valley mapping units. Application of OM in the plain or valley mapping units may ensure slow release of the micronutrients at levels which are sufficient to support plant growth during and or after the implementation of the Expanding Rice Production Project (ERPP) irrigation development.

Keywords: [ERPP, pH, cation exchange capacity, rice, soil microelements, management practices, soil organic matter, survey]

Comment [H2]: At what scale is the survey

Comment [H3]: The survey you conducted was not detailed because profile pit was not dug and also parameter like mineralogical analysis was conducted and the soils were not classified

Comment [H4]: Rearrange it in this format, Not significant ($P \leq 0.05$)

Comment [H5]: This statement is not correct, the Fe content in the two location is >20 mg/kg which is high.

Comment [H6]: acidic

Comment [H7]: This should come first before presenting the status of microelements.

Comment [H8]: This study did not report low OM, while recommending its addition. Recommendation should be based on the study findings. Though it is established that OM correlate with microelement but should only be recommended when it is deficient

Comment [H9]: The keywords are much, reduce it to four. cation exchange capacity and soil organic matter were not assess in this study, it should not be part of the key words.

1. INTRODUCTION

Soil fertility which is determined by the absence or presence of balanced mineral elements i.e. macro and micronutrients is an important factor for plant growth and development. Micronutrients in soils, also referred to as trace elements (TEs), microelements or heavy metals are mineral elements required by plants in small quantities to orchestrate a range of physiological functions [1; 2; 3; 4]. In soils, these micronutrients occur in soils at concentrations < 100 mg kg^{-1} with density > 5 mg m^{-3} [5; 6] and to large extent belong to the group of "transition elements" of the periodic table. Although microelements such as Iron (Fe), Zinc (Zn) and Manganese (Mn) are required in minute quantities by plants for growth and development [7], their availability varies [8] and their uptake in excess to the plant requirements results in toxic effects [9; 10]. In global terms, Sillanpää [11] estimated that the area of micronutrient - deficient in agricultural soils is 49 % in Zn, 10 % in Mn and 3 % in Fe. As a result, more than half the human population is deficient in Fe and at least half is deficient in Zn [12].

Iron (Fe) is an essential micronutrient for almost all living organisms because it plays critical role in metabolic processes such as DNA synthesis, respiration, and photosynthesis. Iron is the fourth most abundant element in the earth's crust but it is the third-most limiting nutrient for plant growth primarily due to its low solubility in aerobic environments [13; 14]. In fact, over one third of the world's soils are

Comment [H10]: This does not flow with the sentence above. It gave an impression that Fe is more deficient than Zn which is not correct, recast

considered Fe deficient. Iron is essential for chlorophyll development and function, energy transfer within the plant, a constituent of many enzymes and proteins, functions in plant respiration, plant metabolism and N₂-fixation. Without sufficient Fe, carbon (C) cannot be extracted from CO₂ and O₂ cannot be properly used in the plant. The yellow and red colors of most soils are caused by Fe compounds, and so, most soils possess enough Fe for plant needs. Fe gives the soil its characteristic color as a result of leaching of other soluble elements leaving Fe behind. Although abundant in most well-aerated soils, the biological activity of Fe is low because it primarily forms highly insoluble ferric compounds at neutral pH levels. Occasionally, rice grown in a low Fe paddy soil can become deficient in Fe due to precipitation of FeS. Iron deficiency is therefore a yield-limiting factor with major implications for field crop production in many agricultural regions of the world [15]. This can be easily corrected by addition of old nails or other iron source to the soil.

Comment [H11]: Verify this statement and add citation/source

Comment [H12]: Verify this statement and add citation/source

Comment [H13]: source

Zinc (Zn) is a metal of over 300 enzymes [16; 17] and is considered to be the most critical micronutrient [18; 19] as it affects the synthesis of protein, structure and functions of membrane [20], expression of genes and oxidative stress tolerance in plants [17; 21]. Zinc is required to maintain the integrity of ribosome and takes part in plant development due to its catalytic action in metabolism for all crops [22; 23]. Several enzymes such as carbonic anhydrase, alcohol dehydrogenase, superoxide dismutase and RNA polymerase contain Zn. Similarly, Zn takes part in the formation of carbohydrates and catalyzes the oxidation processes in plants, provides a structural role in many transcription factors and is a cofactor of RNA polymerase. Therefore, Zn deficiency reduces plant growth and inhibits photosynthesis in many plants [24], fiber crops [25], rice [26], and spinach [27]; retards the activity of carbon metabolism enzymes such as carbonic anhydrase [25; 28], ribulose 1,5-bisphosphate carboxylase/oxygenase and fructose-1,6-bisphosphate [18].

Comment [H14]: Recast this statement

Zinc deficiency not only retards growth and yield of plants, but it also has effects on human beings. More than 3 billion people worldwide are suffering from Fe and Zn deficiencies, and this condition is particularly widespread in areas where population is heavily dependent on an unvaried diet of cereal based foods, in which Fe and Zn are stored almost exclusively in the husk, and are therefore lost during milling and polishing [29; 30]. More than 30 % world's population suffers from Zn deficiency [31]. Zinc plays a part in the basic roles of cellular functions in all living organisms and is also involved in improving the human immune system. The optimum dietary intake for human adults is 15 mg Zn per day. Zinc acts as a catalytic or structural component in various body enzymes. Unsatisfactory intake and improper absorption of Zn in the body may cause deficiency of Zn. Due to Zn deficiency, the human body will suffer from hair and memory loss, skin problems and weakness in body muscles. Further insufficient intake of Zn during pregnancy also causes stunted brain development of the fetus. Infertility has also been observed in Zn deficient men. Zinc deficiency may cause congenital diseases like *Acrodermatitis enteropathica* [32; 33; 34].

Comment [H15]: Source (Citation required)

Manganese (Mn) plays an important role in reactions of enzymes like malic dehydrogenase and oxalosuccinic decarboxylase. It is also needed for water splitting at photosystem II and for superoxide dismutase. In plants, Co complex is found in the form of vitamin B12. The cation Mn²⁺ is known to substitute Fe²⁺ and Mg²⁺ in silicates and oxides. Manganese is essential to organisms, including microorganisms, plants, animals, and human beings. It is involved in many physiological and biochemical processes in plants as a cofactor of enzymes or as a catalyst and is thus a required trace mineral for all known living organisms. Little information is available on Fe, Zn and Mn status in Unguja and Pemba Islands. Understanding the status of these micronutrients will provide valuable information leading to improvements in micro-fertilizer management practices in the selected irrigation schemes

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2. MATERIAL AND METHODS

2.1 Study area

Comment [H18]: Geographic coordinate of the area is very important and also map showing the study area.

The study areas include four (4) irrigation schemes in Pemba and five (5) irrigation schemes in Unguja Islands. The four irrigation schemes in Pemba include Machigini, Dobi, Ole and Kwalempona. Machigini is located in Mkoani; Dobi and Ole are located in Chakechake (Pemba South) and Kwalempona in Wete (Pemba North). The five irrigation schemes in Unguja include Bandamaji in Kaskazin A (Kaskazin); Koani and Mchangani in Central district (Unguja South); Mtwango and Kibonde Mzungu in Magharib B (Unguja West). The project areas receive seasonal rainfall ranging from 1,553 mm in Pemba Airport to 1,926 mm annum⁻¹ in Wete, Pemba. Average yearly rainfall

amounts to about 1,769 mm as compared with 1,449 mm annual evapotranspiration. The rainfall pattern is characteristically bi-modal with two rain seasons separated by dry season. Short rains (Vuli) begin October and end in December while long rains (Masika) usually start in March and ends in May. In Pemba survey areas, Masika rains comprise of an average of 57 % of the total rains compared with Vuli which comprise of 22 % of the total rains. Similarly, Masika rains in Unguja surveyed areas comprise of an average of 50 % compared with Vuli which comprise of 29 % of the total rains. Some of the study areas experiences seasonal flooding on the most of the valleys in some years.

The climate variables representative of the study areas in Pemba and Unguja are presented in Table 4. In Pemba, the mean temperature varies from 26.6°C in July/August to 29.6°C in February. The monthly average relative humidity (RH) varies from 75 % (i.e. July/August) to 83.0 % (i.e. April and November). The potential evaporation is about 1,449 mm per annum and varies widely throughout the year from 97 to 145 mm per month in July and January respectively. In Unguja, the mean temperature varies from 24.9°C in September to 28.4°C in February. The monthly average relative humidity (RH) varies from 78 % in August to 86 % in April. The potential evaporation is about 2,386 mm per annum and varies widely throughout the year from 177.9 to 225.5 mm per month in May and January respectively.

Comment [H19]: There are no information on climate in Table 4. Ideally, you should have a Table of climatic variable if you want so show the data and should read Table 1. Note Table should follow immediately they are mentioned in a page.

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2.2 Soil samples collection and preparation

Base maps were prepared following pedogeomorphic approach indicating mapping units representing landforms. Conventional soil mapping techniques were used to collect soil sample from natural pedogenic horizons. Eighteen (18) topsoil samples (i.e. composite samples) were collected from different mapping unit at each representative profile or minipit at a depth of 0 – 30 cm of the selected irrigation schemes in Pemba and Unguja Islands. The depth (cm) of natural horizons, colours and soil structure were determined using FAO Guidelines for Soil Description [35]. The soil samples were air-dried for 10 consecutive days in the soil chemistry laboratory of the National Soil Service Mlingano, Tanga, Tanzania (NSS) and later sieved to pass through a 2 mm sieve to remove debris. Part of the air-dried soil samples were oven dried to a constant mass at a temperature of 105°C for 24 hours. These were used for all the chemical and physical analysis.

Comment [H21]: I will advice you delete this sentence as you are dealing with surface sample and not profile pit of standard size of 1.5 * 1.5*2 m.

Comment [H22]: Minipit of 30 cm can not represent profile pit, this is surface sample and not profile pit.

Comment [H23]: This is not also needed in your study, since you are not dealing with standard profile pits.

Comment [H24]: Be specific to microelement as their are many plant-available minerals in the soils.

2.3 Determination of Plant-available Minerals in Soils

The trace elements Fe, Zn and Mn were extracted from soil using di-ammonium ethylenediaminetetraacetic (EDTA) acid solution [36] modified by Beyers and Coetzer [37]. The extractants were analysed for Fe, Zn and Mn using ICP-MS spectrometry (IRIS/AP HR DUO Thermo Electron Corporation, Franklin, Massachusetts, USA).

Comment [H25]: Methods for pH determination is missing.

2.4 Statistical Analysis

The statistical analysis was performed using the 2-way analysis of variance (ANOVA) in factorial arrangement, with the computations being performed with the software program STATISTICA. The fisher's least significance difference (L.S.D.) was used to compare treatment means at $P \leq .05$ level of significance [38].

3. RESULTS AND DISCUSSION

3.1 Unguja

3.1.1 Dobi Irrigation Scheme

Results of the status of microelements in the selected irrigation schemes in Unguja are presented in Tables 2-1, 2-2, 2-3 and 2-4. The data showed that Fe, Zn and Mn were different ($P \leq .05$) within the mapping units but not pH. In Dobi Irrigation scheme, Mn ranged from 4.7 to 6.3 mg kg⁻¹, and was greater ($P \leq .05$) in DB - Hi1 compared with the other mapping units. The proposed deficiency levels for Mn (DTPA) in the soil are 1.0 - 5.0 mg·kg⁻¹ and the values greater than 140 - 200 mg·kg⁻¹ were regarded as excess [11;39; 40]. The observed levels of DTPA extractable Mn in this study were therefore considered as normal or sufficient for plant growth and development [40].

Comment [H26]: You should specify if the difference is statistically significant or not

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Comment [H28]: This level is rated medium based on USDA (1993) rating, which implies your study soils are medium to high in Mn.

However, Fe and Zn were comparatively greater ($P \leq .05$) in DB - Va11 and DB - Va12 compared with DB - Hi1 mapping unit. Likewise, the data showed that Zn ranged from 0.5 – 0.7 mg kg⁻¹ and Fe from 26.1 – 32.9 mg kg⁻¹. These were rated as low and very high for DTPA extractable Zn and Fe respectively [41]. The proposed critical levels for DTPA extractable Fe in the soil for instance, ranged from 0.3 – 10 mg kg⁻¹ [11; 40; 42; 43]. Nevertheless, Fe toxicity or deficiency could occur at low and high pH, respectively. From this study the level of DTPA extractable Fe was 32.9 mg kg⁻¹ which was rated as above the critical levels. Higher levels of DTPA extractable Fe may pose soil fertility problems such as P - fixation, B deficiency, Fe and Mn toxicity [44; 45; 46]. The critical values of Zn were 2.0 - 5.0 mg kg⁻¹ and the values greater than 10 - 20 mg kg⁻¹ were regarded as excess [11]. In this study, DTPA extractable Zn showed to be below the critical levels which may affect crop production. The low level of DTPA extractable Zn in DB irrigation scheme was probably attributed to pH whereby Zn showed to decrease as pH increased just as previously reported by Kiekens [47]. Low Zn in the study area could also be due to seasonally flooded soil conditions [48] as a result of Zn reaction with free sulphide [49]. Under the submerged conditions of rice cultivation for example, Zn is changed into amorphous sesquioxide precipitates or franklinite; ZnFe₂O₄ [50].

Table 2-1: The status of some microelements in Dobi Irrigation Scheme in Unguja Island

	pH		Mn	Zn	Fe
	(H ₂ O)	(KCl)	mg.kg ⁻¹		
DB-Va11	5.73a	4.52a	4.68c	0.73a	32.90a
DB-Va12	5.43a	5.33a	5.59b	0.54a	29.98a
DB-Hi1	6.33a	4.43a	6.30a	0.50b	26.12b
One - Way ANOVA (<i>F-Statistic</i>)					
MU	1.8ns	3.2ns	25.5**	49.8***	15.6**
CV (%)	10.0	10.0	5.0	5.1	5.0

Values followed by dissimilar letters in the same column are significant at $P \leq .05$; CV = Coefficient of variation; KCl = Potassium Chloride; H₂O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron

3.1.2 Kwalempona Irrigation Scheme

In Kwalempona Irrigation Scheme, DTPA - extractable Fe ranged from 23.5 mg kg⁻¹ in KWA - Hi1 to 36.3 mg kg⁻¹ in KWA - Va11 (Table 2-2). Results show that DTPA - extractable Fe was greater ($P \leq .05$) in KWA - Va11 compared with the rest of the mapping units. The proposed critical level for various crops varied from 0.3 to 10 mg kg⁻¹ [42] suggesting that Fe in the study area was above the critical limits, thus, sufficient for crop growth. Whereas Mn was greater ($P \leq .05$) in KWA - Hi1 compared with the other mapping units, Zn was lowest ($P \leq .05$) in KWA - Hi1 compared with KWA - Va11 and KWA - Va12 mapping units located in the valley landscape. These values ranged from 4.8 mg kg⁻¹ in KWA - Va11 to 19.9 mg kg⁻¹ in KWA - Hi1 and 0.2 mg kg⁻¹ in KWA - Hi1 to 0.4 in KWA - Va11 for Mn and Zn respectively. The proposed deficiency level for DTPA extractable Mn in the soil varied from 2.0 - 5.0 mg kg⁻¹ with values > 140 - 200 mg kg⁻¹ regarded as excess [11]. These values are rated as within or above the critical limits but not excess for crop growth. The proposed deficiency level for Zn (DTPA) in the soil was 0.4 - 0.6 mg kg⁻¹ and values greater than 10 - 20 mg kg⁻¹ were regarded as excess [11]. Based on this rating, all mapping units in Kwalempona irrigation scheme had adequate Zn levels in the soil for crop growth and development.

Table 2-2: The status of some microelements in Kwalempona Irrigation Scheme in Unguja Island

	pH		Mn	Zn	Fe
	(H ₂ O)	(KCl)			
	mg.kg ⁻¹				
KWA-Va11	5.9a	5.2a	4.8b	0.4a	36.3a
KWA-Va12	6.0a	5.3a	5.7b	0.4a	31.8b
KWA-Hi1	6.9a	6.2a	19.9a	0.2b	23.5c

Comment [H29]: Source. To be more specific check Jimoh et al (2015) for relationship between soil pH and micronutrients. Check <https://geography.abu.edu.ng/journal/2015/02.php>

Comment [H30]: You only stated the highest instead of the range of value.

Comment [H31]: high and was above the critical limit.

Comment [H32]: 1-5 mg/kg not 2-25 mg/kg

Comment [H33]: delete

Comment [H34]: Level of significant need to be define under foot note. What does ** and *** signifies in all the table.

Comment [H35]: I will advice you discuss each element saperately as you did in Fe, rather than combing them.
Follow this format; a)state the range of the value and specify if the difference between the locations are significant or not. b)rate the element to either low, medium or high. c) state the implication of your rating and relate your finding with previous studies. Apply this format for all the locations.

Comment [H36]: The values of Zn in this study is low and not adequate. It is lower than the crtical range of 0.4 – 0.6 mg/kg and also lower than 1 mg/kg reported by USDA (1993)

One- Way ANOVA (F-Statistic)

MU	2.6ns	3.4ns	571.1***	132.8***	52.6***
CV (%)	9.8	10.0	6.1	5.2	5.1

Values followed by dissimilar letters in the same column are significant at $P \leq .05$; CV = Coefficient of variation; KCl = Potassium Chloride; H₂O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron

3.1.3 Machigini Irrigation Scheme

In Machigini Irrigation Scheme there was significant ($P \leq .05$) difference between the mapping units in the Fe, Zn and Mn (Table 2-3). The data showed that the status of DTPA extractable Fe ranged from 21.96 mg kg⁻¹ in MA - Hi1 to 30.31 mg kg⁻¹ in MA - Va2 located in the Hilland and Valley landscapes respectively. Results further showed that Fe was lowest ($P \leq .05$) in MA - Hi1 compared with the rest of the mapping units. These values were rated as high and adequate as they were all above the critical levels as suggested by Page et al. [41] and Lindsay and Cox [42]. Sims and Johnson [51] and Tandon [52] indicated that the critical levels of available Fe for crop production are 2.5 - 4.5 mg kg⁻¹. The high levels of Fe in all the surveyed mapping units in Machigini irrigation scheme could be attributed to the low pH and nature of the parent material from which the soil were formed [53; 54] which may contain minerals like Feldspar, Magnetite, Hematite and Limonite [55]. These results suggest that DTPA - extractable Fe status in Machigini Irrigation scheme is not a threat to crop production.

DTPA - extractable Zn levels ranged from 9.6 mg kg⁻¹ - 16.8 mg kg⁻¹ and were lowest ($P \leq .05$) in MA - Va1 compared with the other mapping units. These values were rated as high [56]. The proposed deficiency level for DTPA extractable Zn in the soil is 0.4 - 0.6 mg kg⁻¹ and values greater than 10 - 20 mg kg⁻¹ were regarded as excess [11] although some studies [57; 58; 59] have reported that the maximum permissible limit for DTPA extractable Zn in soils is 10 to 300 mg kg⁻¹. However, in all the surveyed sites in Machigini irrigation scheme, Zn levels in the soil were in excess. The observed excess DTPA - extractable Zn levels in the study area could be attributed to acidic condition of the soil and low content of free Fe, Al and Mn ions which leads to less adsorption of Zn to non - exchangeable form on their hydrated oxides surface [60] or increased efficiency of heavy metals adsorption by permanent charge soil colloids due to the presence of other divalent cations such as Ca²⁺ [61] or high soil iron (Fe) level and sometimes a high soil Mn level.

The status of DTPA - extractable Mn in Machigini irrigation scheme ranged from 9.58 mg kg⁻¹ - 16.8 mg kg⁻¹. This value was lowest in MA - Va1 compared with the rest of the mapping units. The proposed deficiency level for DTPA - extractable Mn in the soil varied from 2.0 - 5.0 mg kg⁻¹ with excess being values greater than 140 - 200 mg kg⁻¹ [11]. Sims and Johnson [51] indicated that the critical or threshold level of available Mn for crop production is 1 - 50 mg kg⁻¹. Based on the rating, Mn in Machigini Irrigation Scheme was rated as high [62] and adequate for plant growth as it was above the critical levels but not in excess. Tisdale et al. [56] categorized Mn as follows: 0 - 0.5 as low, 0.6 - 1.0 as medium and > 1.0 as high. Based on the above mentioned critical ranges, all soils under the study have DTPA - extractable Mn content higher than the critical limit of 1.0 mg kg⁻¹ as reported by Tisdale et al. [62]. The high levels of Mn in the soils could be due to low pH that favors the dissolution of Mn minerals in soils [53].

Table 2-3: The status of some microelements in Machigini Irrigation Scheme in Unguja Island

	pH (H ₂ O)	pH (KCl)	Mn	Zn	Fe
	mg.kg ⁻¹				
MA-Va1	5.10a	4.40a	9.58c	0.65a	27.92b
MA-Va2	5.10a	4.38a	16.80a	0.48b	30.31a
MA-Hi1	5.73a	5.03a	14.50b	0.50b	21.96a
One - Way ANOVA (F-Statistic)					
MU	1.5ns	1.9ns	83.8***	36.0***	30.6***

Comment [H37]: Cross check this values of Zn with Table 2-3.

Comment [H38]: Cross check

Comment [H39]: The level of Zn is low and not high as they are all less than 1.0 mg/kg

Comment [H40]: This should be recast to support the claim that Zn is low.

CV (%) 9.7 10.0 5.1 5.1 5.0

Values followed by dissimilar letters in the same column are significant at $P \leq .05$; CV = Coefficient of variation; KCl = Potassium Chloride; H₂O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron

3.1.4 Ole Irrigation Scheme

In Ole irrigation scheme, there was significant ($P \leq .05$) difference between the mapping units in the Fe, Zn and Mn contents (Table 2-4). Results showed that DTPA – extractable Fe ranged from 43.7 to 52.9 mg kg⁻¹ and was rated as high [41]. The critical DTPA – extractable Fe content beyond which crop growth is impaired is 4.5 mg kg⁻¹ [52]. The EDTA - extractable Fe was lowest ($P \leq .05$) in OLE - Pa1 located on the Plain landscape compared with other mapping units. These results suggest that DTPA – extractable Fe is not a constraint in crop growth and production in all the mapping units in Ole irrigation scheme.

The data showed that the status of DTPA – extractable Zn ranged from 0.6 to 0.8 mg kg⁻¹ and was rated as low [41; 56]. Similar to Fe, the EDTA - extractable Zn was lowest ($P \leq .05$) in OLE - Pa1 located on the Plain landscape compared with other mapping units. The critical Zn content beyond which crop growth is impaired is 1 mg kg⁻¹ [65]. The low Zn contents in the surveyed mapping units in Ole irrigation scheme probably is due to high content of free Fe, Al and Mn ions which caused adsorption of Zn to non - exchangeable form on their hydrated oxides surface [60]. MacBride [61] observed that the presence of other divalent cations such as Ca²⁺ greatly reduces the efficiency of heavy metals adsorption by permanent charge soil colloids.

Results also showed that DTPA – extractable Mn in the surveyed mapping units in Ole irrigation scheme ranged from 7.7 to 14.9 mg kg⁻¹ and was rated as high [62]. The DTPA - extractable Mn was lowest in OLE – Pa2 compared with other Mapping units. The critical DTPA - extractable Mn level beyond which crop growth is affected is 1 mg kg⁻¹ [62]. The proposed deficiency level for Mn (DTPA) in the soil varied from 2.0 - 5.0 mg kg⁻¹ with values > 140 - 200 mg kg⁻¹ regarded as excess [11]. These results suggest that Mn is not a limiting factor for crop production in the study area.

Table 2-4: The status of some microelements in Ole Irrigation Scheme in Unguja Island

	pH		Mn	Zn	Fe
	(H ₂ O)	(KCl)			
				mg.kg ⁻¹	
OLE-Pa1	5.87a	5.16a	14.87a	0.59c	43.07c
OLE-Pa2	5.37a	4.67a	7.66c	0.82a	52.89a
OLE-Pa3	5.63a	4.92a	11.26b	0.71b	47.98b
One- Way ANOVA (<i>F-Statistic</i>)					
MU	0.6ns	0.7ns	114.9***	31.1***	12.5**
CV (%)	9.8	17.5	5.2	5.0	5.0

Values followed by dissimilar letters in the same column are significant at $P \leq .05$; CV = Coefficient of variation; KCl = Potassium Chloride; H₂O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron

3.2 Pemba

3.2.1 Bandamaji Irrigation Scheme

Results of the status of microelements in the selected irrigation schemes in Pemba are presented in Tables 3-1, 3-2, 3-3 and 3-4. These irrigation schemes are Bandamaji, Koani, Mchangani, Mtwango and K/Mzungu and were selected for irrigation development as prioritized by ERPP program in Unguja and Pemba Islands. Overall, the data showed that Fe and Zn were different ($P \leq .05$) within

Comment [H41]: This is correct and agree with the ratings of USDA (1993) but is contrary to your earlier results of Zn in Machigini and Kwalempona

Comment [H42]: Cross check the level of Fe as it is not significantly different based on Table 3-1

the mapping units but not pH, Fe and Mn. In Bandamaji Irrigation scheme, pH ranged from 5.9 - 6.8 and was rated as medium to very slightly **acid**. DTPA – extractable Zn ranged from 0.36 to 0.46 mg kg⁻¹, and was comparatively greater ($P \leq .05$) in BM-CSMP1 compared with the other mapping units which were not ($P \leq .05$) different. These values were rated as very low and deficient for plant growth and development [40; 41; 56] compared with the proposed critical level that range between 1 - 5 mg kg⁻¹ beyond which crop growth is affected [39; 40; 65]. It has also been reported that values above 10 – 20 mg.kg⁻¹ are considered as excess [11; 40] and may lead to Zn toxicity. The very low level DTPA - extractable Zn in the survey area was probably due to high Zn fixation and/or low Zn solubility as a result of pH. The mechanism involved is that as pH values increases, the ionic forms of Zn or Fe cations are changed to the hydroxides or oxides which are insoluble, making them unavailable to plant for growth [(Fe²⁺ (soluble) + 2OH⁻ → Fe (OH)₂ (insoluble)] [63; 64; 66]. Likewise, high content of free Fe, Al and Mn ions which caused adsorption of Zn to non-exchangeable form on their hydrated oxides surface and the presence of other divalent cations such as Ca²⁺ greatly reduces the efficiency of heavy metals adsorption by permanent charge soil colloids as reported by MacBride [61] and Phogat et al. [60].

Although Fe and Mn were not ($P \leq .05$) different within the mapping units in Bandamaji irrigation scheme Fe ranged from 26.2 - 28.9 mg kg⁻¹ and was rated as high [41]. According to Tandon [52], the critical limit of Fe for crop growth was pegged at 4.5 mg kg⁻¹ beyond which crop growth is affected. Similarly, Mn ranged from 4.4 - 8.6 mg kg⁻¹ rated as high [62]. The critical limit for Mn beyond which crop growth is affected is 1 mg kg⁻¹ [62]. This suggests that DTPA - extractable Fe and Mn in the study area are not limiting factors for crop growth and development.

Table 3-1: The status of some microelements in Bandamaji Irrigation Scheme in Pemba Island

Mapping Unit	pH		Mn	Zn	Fe
	(H ₂ O)	(KCl)			
BM-CSMP1	6.8a	4.9a	5.84a	0.43a	28.90a
BM-CSMP2	5.9a	4.9a	8.59a	0.42a	26.23a
BM-CSP1	6.2a	5.3a	4.40a	0.36b	26.63a
One- Way ANOVA (<i>F</i>-Statistic)					
MU	1.5ns	0.6ns	2.8ns	10.0*	3.3ns
CV (%)	10.0	10.0	35.4	5.0	5.0

Values followed by dissimilar letters in the same column are significant at $P \leq .05$; CV = Coefficient of variation; KCl = Potassium Chloride; H₂O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron

3.2.2 Koani Irrigation Scheme

Results showed that the soils in Koani irrigation scheme were uniformly distributed and variation in mapping units was not observed (Table 3-2). In this irrigation scheme, overall soil pH was 6.04, Fe was 38.5 mg kg⁻¹, Zn was 0.5 mg kg⁻¹ and Mn was 2.3 mg kg⁻¹. These values were rated as slightly **acid**, high, low and high for pH, Fe, Zn and Mn respectively. Based on the critical limits for Fe [52] and Mn [62] the data show that these mineral elements are sufficient and that they are not limiting for crop growth. DTPA extractable Zn was rated as low and deficient, as it was below the proposed critical limit that range between 1 - 5 mg kg⁻¹ beyond which crop growth is affected [41; 40; 65]. These results suggest that Zn should be considered in the fertilizer management program in Koani irrigation scheme.

Comment [H43]: acidic

Comment [H44]: acidic

Comment [H45]: Recast this sentence

Table 3-2: The status of some microelements in Koani Irrigation Scheme in Pemba Island

	pH		Mn	Zn	Fe
	H ₂ O	KCl	mg.kg ⁻¹		
	Total				
	6.04±0.35a	5.34±0.31a	2.32±1.25a	0.51±0.01a	38.47±1.11a

KCl = Potassium Chloride; H₂O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron

3.2.3 Mchangani Irrigation Scheme

Results of soils microelements status in Mchangani irrigation scheme showed that the surveyed area has two mapping units (Table 3-3). Data from the table shows that Fe was ($P \leq .05$) different between the mapping units but not pH, Zn and Mn and was higher in MCH-CSP2 compared with MCH-CSP1. Soil pH range between 5.1 – 5.5; Fe from 26.9 – 41.1 mg kg⁻¹, Zn was 0.42 mg kg⁻¹ and Mn from 4.8 – 5.1 mg kg⁻¹. These values were rated as strongly acid, high, low and high for pH, Fe, Zn and Mn respectively. Based on the critical limits for Fe [52] and Mn [62] the data show that these mineral elements are sufficient and that they are not limiting for crop growth. Similar to Koani irrigation scheme, DTPA extractable Zn was rated as low and deficient, as it was below the proposed critical limit that range between 1 - 5 mg kg⁻¹ [41; 40; 65]. Similar to Koani irrigation scheme, Zn should also be included in the fertilizer management program in Mchangani irrigation scheme.

Table 3-3: The status of some microelements in Mchangani Irrigation Scheme in Pemba Island

	pH		Mn	Zn	Fe
	(H ₂ O)	(KCl)		mg.kg ⁻¹	
MCH-CSP1	5.49a	4.49a	5.07a	0.42a	26.87b
MCH-CSP2	5.05a	4.05a	4.77a	0.42a	41.10a
One- Way ANOVA (<i>F</i> -Statistic)					
MU	1.1ns	1.6ns	0.1ns	0.0ns	100.8***
CV (%)					

Values followed by dissimilar letters in the same column are significant at $P \leq .05$; CV = Coefficient of variation; KCl = Potassium Chloride; H₂O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron

3.2.4 Mtwango and Kibanda Mzungu Irrigation Schemes

Results showed that the soils in Mtwango and Kibanda Mzungu irrigation schemes were uniformly distributed and variation in their respective mapping units was not observed (Table 3-4). In these irrigation schemes, overall soil pH ranged between 5.73 - 5.80, Fe from 24.15 – 32.90 mg kg⁻¹, Zn between 0.37 – 0.73 mg kg⁻¹ and Mn between 4.68 - 5.62 mg kg⁻¹. These values were rated as medium acid, high, low and high for pH, Fe, Zn and Mn respectively. Just as observed in Koani irrigation scheme, and based on the critical limits for Fe [52] and Mn [62] the data show that these mineral elements are sufficient and that they are not limiting for crop growth. DTPA extractable Zn was rated as low and deficient, as it was below the proposed critical limit that range between 1 - 5 mg kg⁻¹ [39; 40; 65]. These results suggest that Zn should be considered in the fertilizer management program in Mtwango irrigation scheme. Similar trend was observed in K/Mzungu irrigation scheme

Table 3-4: The status of some microelements in Mtwango and Kibanda Mzungu Irrigation Scheme in Pemba Island

	pH		Mn	Zn	Fe
	(H ₂ O)	(KCl)			
Mtwango	5.80	4.80	5.62	0.37	24.15
Kibanda Mzungu	5.73	4.52	4.68	0.73	32.90

KCl = Potassium Chloride; H₂O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron

Table 4: Soil fertility data interpretation for ERPP irrigation schemes in Pemba and Unguja Islands (0 - 20 cm)

Scheme	RP	Soil	Land form	S	pH	Soil fertility rating		
		fertility	characterist	(%)	(H ₂ O)	Fe	Zn	Mn
Unit								
symbol								
PEMBA								
Dobi	DB-MP2	Va11	Almost flat	<2	SLA	M	L	H
	DB-P1	Va12	Almost flat	<1	MA	M	L	H
	DB-MP1	Hi1	Sloping	<2	SA	M	L	H
Kwalempona	KWA-MP2	Va1	Almost flat	<2	MA	M	L	H
	KWA-MP3	Va2	Almost flat	<2	N	M	L	H
	KWA-MP1	Hi1	Sloping	2-3	MA	L	L	H
Machigini	MA-P1	Va1	Almost flat	<2	SA	M	L	H
	MA-MP2	Va2	Almost flat	<2	MA	M	L	H
	MA-MP1	Hi1	Sloping	2-3	SA	L	L	H
Ole	OLE-P1	Pa1	Almost flat	0-1	MA	M	L	H
	OLE-MP1	Pa2	Almost flat	0-1	SA	M	L	H
UNGUJA								
K/Mzungu	KBM-P1	Pa2	Almost flat	<2	MA	M	L	H
Bandamaji	BM-P1	Pa1	Almost flat	<2	N	M	L	H
	BM-MP2	Pa2	Almost flat	<2	MA	M	L	H
	BM-MP1	Pa3	Almost flat	<2	SLA	M	L	H
Koani	KN-P1	Pa1	Almost flat	<2	MA	M	L	H
Mchangani	MCH-P1	Pa1	Almost flat	<2	SA	M	L	H
	MCH-P2	Pa2	Almost flat	<2	VSA	M	L	H
K/Mzungu	KBM-P1	Pa2	Almost flat	<2	MA	M	L	H
Mtwango	MTW-P2	Pa1	Almost flat	<2	MA	M	L	H

Based on Mlingano National Soil Service (NSS, 1990) Laboratory guide to general soil fertility evaluation); VL = Very low; L = Low; M = Medium; H = High; N = Neutral soil reaction; SA = Strong acid; VSA = Very strongly acid, MA = Medium acid, SLA = Slightly acid,

Comment [H46]: This is contrary to what you stated in your methods reconcile 20 cm or 30 cm

Comment [H47]: The rating of Fe is not low to medium as stated but high since all the location have value > 4.5 mg/kg

4. CONCLUSION

In conclusion, the status of micronutrients (Fe, Zn and Mn) in the selected ERPP irrigation schemes varied with schemes and the respective mapping units, although in some cases, variations were not statistically significant. In Unguja, with the exception of Dobi and Ole irrigation schemes which had very low or low Zn levels the rest of the schemes had adequate Zn, Fe and Mn. These were not considered as a threat to crop growth and development in all the irrigation schemes in Unguja. In Pemba all irrigation schemes (i.e. Bandamaji, Koani, Mchangani, Mtwango and Kibanda Mzungu) had low Zn and adequate Fe and Mn mineral elements. In addition, the overall soil reaction in these irrigation schemes ranged from neutral (N) to very strongly acid (VSA). In order to improve crop production in the study area, low Zn availability should be addressed by including it into fertilizer programs as well as proper soil pH management through liming in the higher elevations and addition of organic matter in the plain or valley mapping units. Application of organic matter in the plain or valley mapping units may ensure slow release of the micronutrients at levels which are sufficient to support plant growth during and or after the implementation of the anticipated irrigation development.

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Comment [H48]: Note Zn was low in all the soils.

Comment [H49]: acidic

Comment [H50]: This study did not report low OM, why recommending its addition. Recommendation should be based on the study findings.

Comment [H51]: Page N0

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Comment [H52]: Delete

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