

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

Comment [B1]: Which country is Zanzibar in Africa ?

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 at a scale of 1:10,000 was conducted using pedogeomorphic approach from which composite soil samples were collected at a depth of 0 – 30 cm. Each mapping unit had a representative profile around which soil samples were collected at a radius of 20 – 30 m 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 significant ($P \leq 0.05$). 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 high or above critical limits. Additionally, the overall soil reaction in these irrigation schemes ranged from neutral (N) to very strongly acidic (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 for 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

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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]. In soils, these micronutrients occur in soils at concentrations $< 100 \text{ mg kg}^{-1}$ with density $> 5 \text{ mg m}^{-3}$ [4] 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 [5], their availability varies [6] and their uptake in excess to the plant requirements results in toxic effects [7]. In global terms, Sillanpää [8] 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 [9].

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 [10]. In fact, over one third of the world's soils are 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 [11]. 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 [12]. 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 [13]. This can be easily corrected by addition of old nails or other iron source to the soil.

Zinc (Zn) is a metal contained in over 300 enzymes [14] and is considered to be the most critical micronutrient [15; 16] as it affects the synthesis of protein, structure and functions of membrane [17], expression of genes and oxidative stress tolerance in [18]. 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 [19]. 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 [20], fiber crops [21], rice [22], and spinach [23]; retards the activity of carbon metabolism enzymes such as carbonic anhydrase [21; 24], ribulose 1,5-bisphosphate carboxylase/oxygenase and fructose-1,6-bisphosphate [25].

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 is are therefore lost during milling and polishing [26; 27]. More than 30 % world's population suffers from Zn deficiency [28]. 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 [29]. Zinc deficiency may cause congenital diseases like Acrodermatitis enteropathica [30; 31].

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 [32]. 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 [32]. 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.

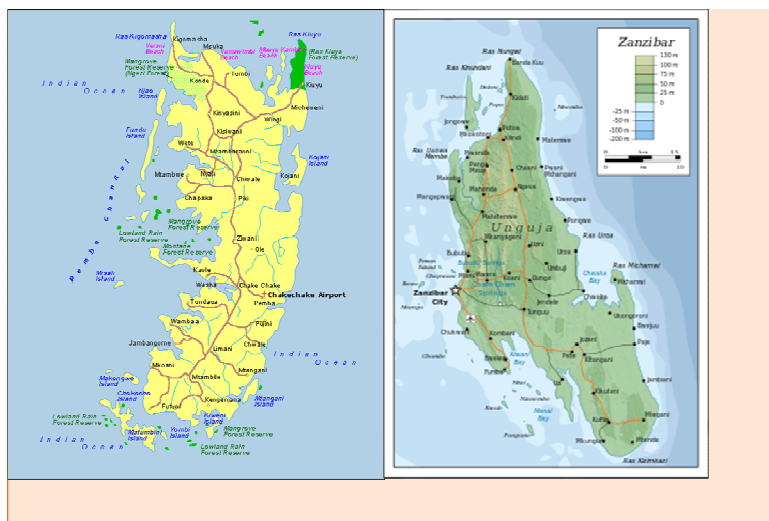
2. MATERIAL AND METHODS

2.1 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

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87 Kwalempona in Wete (Pemba North). The five irrigation schemes in Unguja include Bandamaji in
88 Kaskazin A (Kaskazin); Koani and Mchangani in Central district (Unguja South); Mtwango and
89 Kibonde Mzungu in Magharib B (Unguja West). The administrative map of Pemba and Unguja from
90 which the study was conducted is shown in Figure 1.
91
92



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Figure 1: Pemba (Left) and Unguja (Right) Administrative Map

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 1**. 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.

Table 1: Climatic data representative for Unguja and Pemba ERPP Irrigation schemes

Climate Variable	J	F	M	A	M	J	J	A	S	O	N	D	Total
PEMBA													
Rain (mm) Wete	65.0	47.0	157.0	433.0	456.0	136.0	77.0	47.0	34.0	100.0	223.0	151.0	1,926.0
Rainfall (mm/m) PBA Airport	46.8	31.0	133.5	424.7	404.4	115.2	60.8	35.8	24.6	79.0	92.4	86.5	1,553.1
Rainfall (mm/m) Matangatuani	20.1	28.4	186.1	410.7	434.0	113.9	82.0	54.0	42.1	147.0	181.6	126.5	1,826.6
Mean Min Temp (°C)	25.3	25.1	25.4	25.3	24.7	24.3	23.6	23.5	23.4	23.9	24.6	25.2	
Mean Max Temp (°C)	33.4	34.0	33.5	32.5	31.4	30.3	29.6	29.7	30.7	31.5	32.6	33.4	
Mean Temp (°C)	29.4	29.6	29.5	28.9	28.1	27.3	26.6	26.6	27.1	27.7	28.6	29.3	
Mean RH (%)	78.0	76.0	81.0	83.0	81.0	76.0	75.0	75.0	76.0	77.0	83.0	81.0	
Sunshine (%)	45	35	50	40	35	35	33	35	40	45	40	40	
Day length (h)	12.4	12.3	12.1	12	11.9	11.8	11.8	11.9	12.1	12.2	12.3	12.4	
PET Daily (mm)	4.7	5.0	4.6	3.3	3.3	3.3	3.1	3.5	4.0	4.3	4.1	4.1	

Climate Variable	J	F	M	A	M	J	J	A	S	O	N	D	Total
PET Month (mm)	145	141	143	113	101	100	97	109	120	133	122	125	1,449.0
0.5PET (mm/m)	73	71	72	57	51	50	49	55	60	67	61	63	724.5
Wind (m/s)	1.7	1.4	1.0	1.0	1.1	1.6	1.2	1.3	1.4	1.5	1.3	1.2	
UNGUJA													
Rainfall (mm/m) ZNZ Airport	91.3	76.3	208.8	422.4	297.3	86.8	63.0	62.0	66.7	144.0	215.9	191.3	1,926
Rainfall (mm/m) Kizimbani	81.2	69.5	156.2	404.9	260.9	59.5	40.2	38.8	34.3	101.1	187.5	170.2	1,604
Mean min Temp (°C)	24.1	23.8	24.1	24.2	23.4	22.5	21.5	20.6	20.4	21.5	22.6	23.6	
Mean Max Temp (°C)	32.4	32.9	32.1	30.4	29.5	29.1	28.7	29.2	30.3	31.1	30.8	30.3	
Mean MeanTemp (°C)	28.2	28.4	28.1	27.3	26.5	25.8	25.1	24.9	25.4	26.3	26.7	27.0	
Mean RH (%)	79	79	83	86	84	81	79	78	79	80	85	84	
Sunshine (%)	60.0	65.0	60.0	48.0	59.0	63.0	61.0	71.0	70.0	67.0	60.0	64.0	
Day length (h)	12.4	12.3	12.1	12.0	11.8	11.7	11.8	11.9	12.1	12.2	12.4	12.5	
PET Daily (mm)	5.5	5.8	5.3	4.4	4.6	4.6	4.6	5.1	5.5	5.5	5.0	5.4	
ETo (mm/month)	225.5	217.4	204.2	180.3	177.9	182.7	192.7	202.4	212.8	219.6	177.9	192.5	2,386
0.5ETo (mm/m)	112.7	108.7	102.1	90.2	88.9	91.4	96.3	101.2	106.4	109.8	89.0	96.3	1,193
Wind (m/s)	1.9	1.8	1.8	1.6	2.2	2.3	2.3	2.2	2.2	2.0	1.6	2.0	

Source: Tanzania Meteorological Agency: Rainfall Data (mm) for Pemba Airport (1984 - 2012); Matangatuani (2001-2012); Temp data (1994 – 2012) from Pemba Station, Wete (Latitude 5 04'S, altitude 20 m); TMA Zanzibar RH (1990 – 2013); Rainfall; Temperature and Evaporation (1984 – 2013). Total annual rainfall $\approx$ 1769 mm, Total annual Evaporation (Pan) $\approx$ 1,087 mm (Pemba) and 1,765 mm m⁻¹ Rainfall in Unguja and ETo of 1,789 mm m⁻¹

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) at a depth of 0 – 30 cm were collected from different mapping unit around each representative profile or minipit in 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. 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.

2.3 Soil reaction determination

Soil reaction (pH) was measured potential metrically in a 1:2.5 suspension of soil and water and a 1:2.5 suspension of soil and 1M KC1 (pH KCl)

2.4 Determination of some plant-available micronutrients in soils

The trace elements Fe, Zn and Mn were extracted from soil using di-ammonium ethylenediaminetetraacetic (EDTA) acid solution [33] modified by Beyers and Coetzer [34]. The extractants were analysed for Fe, Zn and Mn using ICP-MS spectrometry (IRIS/AP HR DUO Thermo Electron Corporation, Franklin, Massachusetts, USA).

2.5 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 [35].

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**. Soil reaction in this irrigation scheme ranged from 5.43 in DB-Va12 to 6.33 in DB-Hi1. Although these values were not statistically different, pH was numerically superior in DB-Hi1 compared with the other mapping units. These were rated as slightly acidic to strong acidic. The data showed that Fe, Zn and Mn were statistically ($P \leq .05$) different within the mapping units with the exception of pH but not pH. Fe was comparatively greater ($P \leq .05$) in DB - Va11 and DB - Va12 compared with DB - Hi1 mapping unit. Likewise, the data showed that Fe from 26.1 - 32.9 mg kg⁻¹. These were rated as very high for DTPA extractable Fe [36]. The proposed critical levels for DTPA extractable Fe in the soil for instance, ranged from 0.3 – 10 mg·kg⁻¹ [8; 37; 38; 39]. Nevertheless, Fe toxicity or deficiency could occur at low and high pH, respectively [40; 41]. From this study the higher level of DTPA extractable Fe was 32.9 mg·kg⁻¹ which was rated as high and was above the critical limit. Higher levels of DTPA extractable Fe may pose soil fertility problems such as P - fixation, B deficiency, Fe and Mn toxicity [42; 43].

Zn was 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 were rated as low [36]. The critical values of Zn were 1.0 - 5.0 mg·kg⁻¹ and the values greater than 10 - 20 mg·kg⁻¹ were regarded as excess [8]. 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 [44]. Low Zn in the study area could also be due to seasonally flooded soil conditions [45] as a result of Zn reaction with free sulphide [46]. Under the submerged conditions of rice cultivation for example, Zn is changed into amorphous sesquioxide precipitates or franklinite; ZnFe₂O₄ [47]. Low Zn or deficiency in crops resulting in heavy yield losses has similarly been identified throughout the world including Afghanistan [48] and Australia [49]. Zn deficiency can be corrected by adding Zn compounds to the soil or plant and or intensified breeding efforts to improve the tolerance to Zn deficiency in crops such as rice cultivars [50].

In Dobi Irrigation scheme, Mn ranged from 4.7 to 6.3 mg kg⁻¹, and was significantly ($P \leq .05$) greater in DB - Hi1 compared with the other mapping units. The proposed deficiency levels for Mn (DTPA) in the soil beyond which plant growth is hampered are 1.0 - 5.0 mg·kg⁻¹ and the values greater than 140 - 200 mg·kg⁻¹ were regarded as excess [8; 51; 37]. The observed levels of DTPA extractable Mn in this study were therefore considered as high or sufficient for plant growth and development [37]. Greater amounts of Mn in soils may lead to excessive Mn concentrations in plant tissues and can alter various processes, such as enzyme activity, absorption, translocation and utilization of other mineral elements (Ca, Mg, Fe and P), causing oxidative stress [52].

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

	pH		Fe	Zn	Mn
	(H ₂ O)	(KCl)			
DB-Va11	5.73a	4.52a	32.90a	0.73a	4.68c
DB-Va12	5.43a	5.33a	29.98a	0.54a	5.59b
DB-Hi1	6.33a	4.43a	26.12b	0.50b	6.30a
One - Way ANOVA (F-Statistic)					
MU	1.8ns	3.2ns	15.6**	49.8***	25.5**
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; ** = significant at $P < .01$; *** = significant at $P < .001$; ns = non-significance

3.1.2 Kwalempona Irrigation Scheme

DTPA extractable Fe, Zn and Mn in Kwalempona Irrigation Scheme are presented in Table 2-2. In this scheme, soil pH (H₂O) ranged from 5.9 in KWA-Va11 to 6.9 in KWA-Hi1. Although soil reaction was not significantly different between the mapping units, it was numerically greater in KWA-Hi1 compared with the other mapping units. These were rated as neutral to moderately acidic. DTPA - extractable Fe ranged from 23.5 mg kg⁻¹ in KWA - Hi1 to 36.3 mg kg⁻¹ in KWA - Va11 and was rated as high. Results show that DTPA - extractable Fe was significantly ($P \leq .05$) greater in KWA - Va11

214 compared with the rest of the mapping units. The proposed critical level for various crops varied from
 215 0.3 to 10 mg kg⁻¹ [38] suggesting that Fe in the study area was above the critical limits, thus, sufficient
 216 for crop growth. The high levels of Fe in all soils could partly be attributed to the low pH and nature of
 217 the parent material from which the soil were formed [53]. Zn was significantly ($P \leq .05$) lowest in KWA
 218 – Hi1 compared with KWA - Va11 and KWA - Va12 mapping units located in the valley landscape.
 219 These values ranged from 0.2 mg kg⁻¹ in KWA – Hi1 to 0.4 in KWA – Va11 and were rated as low.
 220 The proposed deficiency level for Zn (DTPA) in the soil was 0.4 - 0.6 mg kg⁻¹ and values greater than
 221 10 - 20 mg kg⁻¹ were regarded as excess [8]. Based on this rating, all mapping units in Kwalempo
 222 irrigation scheme had low Zn levels in the soil for crop growth and development. Zn deficiency has
 223 been associated with a wide range of soil conditions including high pH (7.0), low available Zn content,
 224 and prolonged submergence and low redox potential [54]. Results also showed that Mn was
 225 significantly ($P \leq .05$) greater in KWA – Hi1 compared with the other mapping units. These values
 226 ranged from 4.8 mg kg⁻¹ in KWA - Va11 to 19.9 mg kg⁻¹ in KWA – Hi1 and were rated as high. The
 227 proposed deficiency level for DTPA extractable Mn in the soil varied from 2.0 - 5.0 mg kg⁻¹ with values
 228 > 140 - 200 mg kg⁻¹ regarded as excess [8]. These values are rated as within or above the critical
 229 limits but not excess for crop growth. Similar to Fe, high levels of Mn in the soils could partly be due to
 230 low pH that favors the dissolution of Mn minerals in soils as suggested by [53].

231 **Table 2-2:** The status of some microelements in Kwalempo Irrigation Scheme in Unguja Island
 232

	pH		Fe	Zn	Mn
	(H ₂ O)	(KCl)			
				mg.kg ⁻¹	
KWA-Va11	5.9a	5.2a	36.3a	0.4a	4.8b
KWA-Va12	6.0a	5.3a	31.8b	0.4a	5.7b
KWA-Hi1	6.9a	6.2a	23.5c	0.2b	19.9a
One- Way ANOVA (<i>F</i>-Statistic)					
MU	2.6ns	3.4ns	52.6***	132.8***	571.1***
CV (%)	9.8	10.0	5.1	5.2	6.1

233 Values followed by dissimilar letters in the same column are significant at $P \leq .05$; CV = Coefficient of
 234 variation; KCl = Potassium Chloride; H₂O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron, *** =
 235 significant at $P < .001$; ns = non-significance
 236

237 3.1.3 Machigini Irrigation Scheme

238 In Machigini Irrigation Scheme there was significant ($P \leq .05$) difference between the mapping units in
 239 the Fe, Zn and Mn with the exception of pH (Table 2-3). Results show that pH range from 5.10 in MA-
 240 Va1 and Va2 to 5.73 in MA-Hi1 and were rated as medium acidic to strongly acidic. The data showed
 241 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 -
 242 Va2 located in the Hilland and Valley landscapes respectively. Results further showed that Fe was
 243 significantly ($P \leq .05$) lowest in MA - Hi1 compared with the rest of the mapping units. These values
 244 were rated as high and adequate as they were all above the critical levels as suggested by Page et al.
 245 [36] and Lindsay and Cox [38]. Sims and Johnson [55] and Tandon [56] indicated that the critical
 246 levels of available Fe for crop production are 2.5 - 4.5 mg kg⁻¹. The high levels of Fe in all the
 247 surveyed mapping units in Machigini irrigation scheme could be attributed to the low pH and nature of
 248 the parent material from which the soil were formed [57] which may contain minerals like feldspar,
 249 magnetite, hematite and limonite [58]. These results suggest that DTPA - extractable Fe status in
 250 Machigini Irrigation scheme is not a threat to crop production.
 251

252 DTPA - extractable Zn levels ranged from 0.48 mg kg⁻¹ – 0.65 mg kg⁻¹ and were significantly ($P \leq .05$)
 253 lowest in MA – Va2 compared with the other mapping units. These values were rated as low [59]
 254 [Tisdale et al., 1993]. The proposed deficiency level for DTPA extractable Zn in the soil is 0.4 - 0.6 mg
 255 kg⁻¹ and values greater than 10 - 20 mg kg⁻¹ were regarded as excess [8] although some studies [60]
 256 have reported that the maximum permissible limit for DTPA extractable Zn in soils is 10 to 300 mg kg⁻¹.
 257 However, in all the surveyed sites in Machigini irrigation scheme, Zn levels in the soil were low [59].
 258 The observed low DTPA - extractable Zn levels in the study area could be attributed to high content of
 259

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free Fe, Al and Mn ions which leads to adsorption of Zn to non - exchangeable form on their hydrated oxides surface [61] or reduced efficiency of heavy metals adsorption by permanent charge soil colloids due to the presence of other divalent cations such as Ca^{2+} [62]

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 ($P \leq .05$) 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} [8]. Sims and Johnson [55] 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 [63] and adequate for plant growth as it was above the critical levels but not in excess. Tisdale et al. [59] 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. [63]. The high levels of Mn in the soils could be due to low pH that favors the dissolution of Mn minerals in soils [54].

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

	pH		Fe	Zn	Mn
	(H_2O)	(KCl)		mg.kg^{-1}	
MA-Va1	5.10a	4.40a	27.92b	0.65a	9.58c
MA-Va2	5.10a	4.38a	30.31a	0.48b	16.80a
MA-Hi1	5.73a	5.03a	21.96a	0.50b	14.50b
One - Way ANOVA (<i>F</i>-Statistic)					
MU	1.5ns	1.9ns	30.6***	36.0***	83.8***
CV (%)	9.7	10.0	5.0	5.1	5.1

Values followed by dissimilar letters in the same column are significant at $P \leq .05$; CV = Coefficient of variation; KCl = Potassium Chloride; H_2O = Water; Mn = Manganese; Zn = Zinc; Fe = Iron; *** = significant at $P < .001$; ns = non-significance

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 with the exception of soil reaction (Table 2-4). Soil pH ranged from 5.35 in OLE-Pa2 to 5.87 in OLE-Pa1 and was rated as medium acidic to strong acidic. Results also showed that DTPA - extractable Fe ranged from 43.7 to 52.9 mg kg^{-1} and was rated as high [36]. The critical DTPA - extractable Fe content beyond which crop growth is impaired is 4.5 mg kg^{-1} [57]. The EDTA - extractable Fe was significantly ($P \leq .05$) lowest 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 [59]. Similar to Fe, the EDTA - extractable Zn was significantly ($P \leq .05$) lowest 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 [61]. MacBride [62] observed that the presence of other divalent cations such as Ca^{2+} 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 [63]. The DTPA - extractable Mn was significantly ($P \leq .05$) 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} [63]. 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 [8]. 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		Fe	Zn	Mn
	(H ₂ O)	(KCl)		mg.kg ⁻¹	
OLE-Pa1	5.87a	5.16a	43.07c	0.59c	14.87a
OLE-Pa2	5.37a	4.67a	52.89a	0.82a	7.66c
OLE-Pa3	5.63a	4.92a	47.98b	0.71b	11.26b
One- Way ANOVA (<i>F</i> -Statistic)					
MU	0.6ns	0.7ns	12.5**	31.1***	114.9***
CV (%)	9.8	17.5	5.0	5.0	5.2

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; ** = significant at $P < .01$; *** = significant at $P < .001$; ns = non-significance

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 was significantly ($P \leq .05$) different within the mapping units but not pH, Fe and Mn. In Bandamaji Irrigation scheme, pH ranged from 5.9 - 6.8 and was rated as neutral to medium acidic. Although Fe was not significantly ($P \leq .05$) different within the mapping units in Bandamaji irrigation scheme, Fe ranged from 26.2 - 28.9 mg kg⁻¹ and was rated as high [44]. According to Tandon [57] the critical limit of Fe for crop growth was pegged at 4.5 mg kg⁻¹ beyond which crop growth is affected. This suggests that DTPA - extractable Fe in the study area is not a limiting factor for crop growth and development.

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 [36; 37; 59] compared with the proposed critical level that range between 1 - 5 mg kg⁻¹ beyond which crop growth is affected [52; 37; 64]. It has also been reported that values above 10 - 20 mg.kg⁻¹ are considered as excess [8; 37] and may lead to Zn toxicity. The low level of DTPA - extractable Zn in the survey area was probably due to high Zn fixation and/or low Zn solubility partly as a result of pH. The mechanism involved is that as pH values increases, the ionic forms of Zn cations are changed to the hydroxides or oxides which are insoluble, making them unavailable to plant for growth [Zn^{2+} (soluble) + $2\text{OH}^- \rightarrow \text{Zn}(\text{OH})_2$ (insoluble)] [61; 68]. 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 Ca^{2+} greatly reduces the efficiency of heavy metals adsorption by permanent charge soil colloids as reported by MacBride [61] and Phogat et al. [60].

Although Mn was not significantly ($P \leq .05$) different within the mapping units in Bandamaji irrigation scheme, Mn ranged from 4.4 - 8.6 mg kg⁻¹ and was rated as high [63]. The critical limit for Mn beyond which crop growth is affected is 1 mg kg⁻¹ [63]. This suggests that DTPA - extractable Mn in the study area is not a limiting factor for crop growth and development.

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

Mapping Unit	pH		Fe	Zn	Mn
	(H ₂ O)	(KCl)		mg.kg ⁻¹	
BM-CSMP1	6.8a	4.9a	28.90a	0.43a	5.84a

BM-CSMP2	5.9a	4.9a	26.23a	0.42a	8.59a
BM-CSP1	6.2a	5.3a	26.63a	0.36b	4.40a
One- Way ANOVA (<i>F</i>-Statistic)					
MU	1.5ns	0.6ns	3.3ns	10.0*	2.8ns
CV (%)	10.0	10.0	5.0	5.0	35.4

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; * = significant at $P < .05$; ns = non-significant

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 acidic, high, low and high for pH, Fe, Zn and Mn respectively. Based on the critical limits for Fe [56] and Mn [63] 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 [36; 37; 64]. These results suggest that Zn should be considered in the fertilizer management program in Koani irrigation scheme.

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

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

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 significantly ($P \leq .05$) 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 acidic, high, low and high for pH, Fe, Zn and Mn respectively. Based on the critical limits for Fe [56] and Mn [63] 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 [36; 37; 64]. Just as in 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		Fe	Zn	Mn
	(H ₂ O)	(KCl)	mg.kg ⁻¹		
MCH-CSP1	5.49a	4.49a	26.87b	0.42a	5.07a
MCH-CSP2	5.05a	4.05a	41.10a	0.42a	4.77a
One- Way ANOVA (<i>F</i>-Statistic)					
MU	1.1ns	1.6ns	100.8***	0.0ns	0.1ns
CV (%)	10.0	10.0	5.1	5.0	19.2

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; *** = significant at $P < .001$; ns = non - significance

3.2.4 Mtwango and Kibanda Mzungu Irrigation Schemes

Comment [B6]: Table should only contain horizontal line.

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 acidic, 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 [56] and Mn [63] 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 [37; 51; 64]. These results also 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		Fe	Zn	Mn
	(H ₂ O)	(KCl)	mg.kg ⁻¹		
Mtwango	5.80	4.80	24.15	0.37	5.62
Kibanda Mzungu	5.73	4.52	32.90	0.73	4.68

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 - 30 cm)

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

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, all irrigation schemes had very low or low levels of Zn. However, the rest of the schemes had adequate Fe and Mn. These were not considered 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 **acidic** (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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