Soil Chemical Characterization and Fertility Status in Selected Irrigation Schemes in Unguja and Pemba Isles, Zanzibar

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Abstract: A survey was undertaken to assess the soil chemical properties and fertility status in selected irrigation schemes in Unguja and Pemba Isles in October, 2017 during the short rainy seasons. These schemes include Dobi, Kwalempona, Machigini and Ole in Pemba and Bandamaji, Kibonde Mzungu, Koani, Mchangani and Mtwango in Unguja. Soil sampling was done after the soils were grouped into similar pedons following pedogeomorphic approach whereby fifteen and ten mapping units were delineated in Pemba and Unguja respectively. Using zigzag sampling techniques, nineteen composite samples were collected in quadruplicate at a depth of 0 – 30 cm from the delineated pedogeomorphic units at a radius of 20 m around the soil pits. Soil samples were bulked, thoroughly mixed, sub sampled to obtain a representative sample, packed and sent to NSS laboratory for analysis. The results showed significant difference in fertility status in the selected irrigation schemes. The pH was rated as neutral to strongly acid and or very strongly acid. Of the 25 surveyed mapping units (MUs), 47% were rated as medium acid, 26% as strongly acid, 11% as slightly acid and neutral and 5% as very strongly acid. Per cent OC was high in 21%, medium in 63% and low in 16%. In Machigini irrigation scheme, a third of the MUs was rated as having high % OC compared with the two thirds with medium values. Nitrogen was very low in 89% and low in 11% of the surveyed MUs. Whereas that all the surveyed MUs had N below the threshold value (< 2 g kg⁻¹), 84% had low P and 16% has medium levels of available P. CEC values were rated as medium in 32%, high in 16% and very high in 53% of the MUs surveyed. The C:N ratio suggested that SOM was of poor quality in 89% and moderate in 11% of MUs and all the MUs had C/N ratio outside the suggested range. Nutrient balance shows that Ca/Mg ratio in 58% of the MUs was optimal for most crops and 42% was non-optimal. In conclusion, the soil fertility status and overall information from this study could be used in project irrigation design and fertilizer management studies to establish nutrient and drainage requirements for rice and other crops grown in these areas.

Keywords: Calcium, Cation Exchange Capacity, Fertility Constraints

1. Introduction

Agriculture is by far the most important source of employment and a base for foreign exchange earnings in Pemba and Unguja isles. On average, 70% of the population depends directly or indirectly in the agriculture sector for their livelihood [1]. By implication the sector has high potential for addressing high levels of income poverty, food insecurity and other socio-economic challenges. As a result, the sector deserves adequate public and private sector investment for attaining and maintaining the anticipated high growth rate. However, agricultural production in Unguja and Pemba is small scale, predominantly subsistence and largely rainfed. Unfortunately, rainfall in these areas is too erratic and unreliable for dry season farming, making supplementary irrigation necessary for successful crop growth and
development. Globally, smallholder irrigation systems are viewed as critical for increasing crop water supply and sustained livelihoods in semi-arid regions [2]. Improving agriculture and enhancing productivity through smallholder irrigation is therefore one of the ways for alleviating poverty and improving the livelihoods of rural communities [3]. This is particularly true for Pemba and Unguja Isles where some irrigation schemes have been selected for development under Expanding Rice Production Project (ERPP). It is believed that with irrigation improvement and development, more area will be put under cultivation particularly during the dry season and reach the full irrigation potential of the districts in which the selected irrigation schemes are situated. Reliable availability of crop water requirement through irrigation water during growth of various crops including paddy will contribute significantly to the economic growth, not only for the people within the selected irrigation schemes in Pemba and Unguja Isles, but also will contribute to the overall National Economic Growth. The most commonly grown crops in these schemes are: maize (Zea mays L.), rice (Oryza sativa L.), beans (Phaseolus vulgaris L) and cowpea (Vigna unguiculata L.). Although these crops are commonly grown in the study area, farmers in the selected irrigation schemes have shown interest in paddy cultivation with a view to address food security and economic challenges if irrigation water availability is ensured. As it is well known that irrigation development is an expensive undertaking, detailed feasibility study is mandatory including the fertility status of the areas to be developed for irrigation. This is because nutrients and nutrients balance is of great challenge in most areas of the district just as in similar environments elsewhere [4, 6, 7].

Due to these challenges and other complex soil, crop management, farming systems and soil fertility [8] the average yield of paddy in the study area is 0.4 t ha\(^{-1}\) which is very low compared with a potential of 8 t ha\(^{-1}\) reported elsewhere [4, 9, 10]. Although no studies have been conducted on the assessment of soil chemical properties and fertility in the selected irrigation schemes in Pemba and Unguja Isles irrigation development, experience from studies of similar environments elsewhere in Africa have shown soil fertility decline [7, 11, 12, 13] often leading to low crop production and productivity [14, 15, 16, 17] as may be the case with soils in the ERPP selected irrigation schemes in Pemba and Unguja Isles. Therefore, assessment of soil chemical properties and fertility status in the study areas was necessary and was assessed based on standard key indicators as reported in [18, 19] as are realistic in predicting plant growth and development. Assessment and understanding of the soil fertility status based on the attributes described in Monreal et al. [18] and Brady and Weil [19] will not only enhance strategies for soil fertility management and land development, but also will provide input into the design and planning irrigation infrastructures and crop nutrition packages in the study areas. To date, studies on soil fertility status in Pemba and Unguja Isles are very scarce [5, 13, 20]. The objective of this study was therefore to assess the soil chemical properties and fertility status in the selected ERPP irrigation schemes of Pemba and Unguja Isles.

2. Material and Methods

2.1. Description of Study Area

Machigini, Dobi, Ole and Kwalemonpa Irrigation schemes are located in Pemba which is divided into Pemba North and South. Machigini is located in Mkoani, Dobi and Ole are located in Chakechake in Pemba South, and Kwalemonpa is located in Wete, that is, in Pemba North. 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 – 1,926 mm annum\(^{-1}\) in Wete, Pemba. Figures 1 and 2 shows water balance and the determination of the growing period for the selected schemes at Kizimbani and Zanzibar Airport on one hand and Pemba Airport, Wete Pemba and Matangatuani stations on the other hand. Average yearly rainfall amounts to about 1,769 mm per annum as compared to 1,449 mm as annual evapotranspiration. The rainfall pattern is characteristically bi-modal with two rain seasons separated by dry season (Figures 1 and 2). 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. Farmers in most of the surveyed irrigation schemes in both Pemba and Unguja do not practice irrigation at all. Lack of irrigation and drainage infrastructure is probably the main cause for this problem.
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 145.0 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 86.0% 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 month\(^{-1}\) in May and January respectively.
2.2. Soil Sampling

Soil sampling in the ERPP selected irrigation schemes in Pemba and Unguja was done after the soils were grouped into similar soil types or pedons following pedogeomorphic approach [21] whereby a total of twenty five (25) mapping units were delineated. Of the total (25) mapping units, fifteen (15) were from Pemba irrigation schemes and ten (10) from Unguja irrigation schemes. Using zigzag sampling techniques, nineteen (19) disturbed soil samples were then collected at depth 0 – 30 cm from the delineated pedogeomorphic units. Soil samples from each soil type were bulked, thoroughly mixed, sub sampled to obtain a representative composite sample. After the soil samples were filled in plastic bags and labelled, they were sent for laboratory analysis at the National Soil Service laboratory, Mlingano (NSS), Tanga, Tanzania. In the laboratory, the samples were air dried and then ground to pass through a 2-mm sieve for determination of physical chemical fertility indicators. These disturbed samples were divided into four (4) sub-samples to obtain four (4) replicates after which they were analysed separately.

2.3. Soil Physicochemical Indicators

Particle size analysis was determined by Bouyoucos hydrometer method after dispersion with 5% sodium hexametaphosphate [22] and textural classes were determined using the USDA textural class triangle [23]. Organic carbon was determined by the Walkley and Black wet oxidation method [24] and OC was converted to organic matter (OM) by multiplying by a factor of 1.724 [25]. Soil reaction was measured potentiometrically in water and 1N KCl at a ratio of 1: 2.5 soils: water and KCl [26]. Total nitrogen was determined using micro-Kjeldahl digestion distillation method [27].

Determination of Ca, Mg, K, Na referred to as exchangeable bases and CEC referred to as cation exchange capacity depended on soil reaction. In soils with pH < 7.5, were extracted by saturating soils with 1M ammonium acetate (NH₄OAc) at pH 7, ethanol and acidified 1MKCl in the first percolate [28]. The absorbed NH₄⁺ displaced by K⁺ using 1M KCl was then determined by Kjeldahl distillation method for the estimation of CEC of the soil. For soils with pH > 7.5 and high carbonates contents, the method recommended by [29] was followed. Determination of K and Na was done with flame photometer, Ca and Mg by Inductively Coupled Plasma Atomic Absorption Emission Spectrophotometer [30]. Cation exchange capacity (CEC) was done following the method by [30]. Potentiometric method was used to determine electrical conductivity (EC) of

![Table 1. Climatic data representative for Pemba and Unguja selected ERPP irrigation schemes.](image-url)
soil samples following the procedure described by [31]. The total exchangeable bases (TEB) were calculated arithmetically as a sum of the four exchangeable bases (Ca\(^{2+}\), Mg\(^{2+}\), Na\(^{+}\) and K\(^{+}\)) for a given soil sample. Available P was extracted spectrophotometrically [32] by reacting with ammonium molybdate using ascorbic acid as a reductant in the presence of antimony as in [33]. The total exchangeable bases (TEB) were obtained as the sum of exchangeable Ca, Mg, K and Na. Per cent base saturation (% BS) was obtained by dividing TEB by CEC and then multiplied by 100 [34]. Exchangeable sodium percentage (ESP) was obtained by dividing total exchangeable sodium by CEC, and then multiplied by 100. The K:TEB was obtained by dividing K by TEB.

2.4. Statistical Analysis

One-way ANOVA was used to compare soil mineral elements from the different pedogeomorphic units. The analysis was performed using the STATISTICA software of 2016 version (Stat Soft Inc., Tulsa, OK, USA) [35]. The mean values were compared at 5% level of significance using least significant differences (L.S.D) test.

3. Results and Discussion

3.1. Soil Reaction

Results of the chemical properties of the top soils in the ERPP irrigation schemes in both Pemba and Unguja Islands are summarized in Tables 2, 3 and 4. The data shows that the pH of top soils ranged from 5.1 to 6.9 in Pemba and 5.0 to 6.8 in Unguja. These were rated as neutral (N) to strongly acid (SA) and or very strongly acid (VSA) [36]. Of the 25 surveyed mapping units, 47% were rated as medium acid (i.e. pH: 5.6 – 6.0), 26% were strongly acid (i.e. pH: 5.6 – 6.0), 11% were slightly acid (i.e. pH: 6.1 – 6.5) and neutral (i.e. pH: 6.6 – 7.3), and 5% were very strongly acid (i.e. pH: 4.5 – 5.0) as observed in Mchangani irrigation scheme. The nature of the observed acidity in the majority of these soils threatens the availability of mineral elements such as P which is readily available in soils with pH at 6.5. The very strongly acid observed in 5% of the mapping units can lead to high concentrations of soluble Al, Fe and Mn. Consequently, high levels of these mineral elements may be toxic to the growth of sensitive plants due to Al toxicity [37; 38]. Soils tend to become acidic or strongly acid as a result of (1) leached basic ions (Ca, Mg, K and Na); (2) formation of a weak organic acid as a result of dissolved CO\(_2\) from decomposing OM and root respiration; (3) formation of strong organic and inorganic acids, such as nitric (HNO\(_3\)) and sulphuric (H\(_2\)SO\(_4\)) acids from decaying OM and oxidation of ammonium (NH\(_3\)) and sulphur (S) fertilizers. However, most plant mineral elements are available in the pH range of approximately 6.5 – 7.0 [39]. Similarly, soil pH can influence plant growth by its effect on the activity of beneficial micro-organisms. For example, bacteria that decompose SOM are hindered in strong acid soils which in turn prevent OM from breaking down. As a result, OM is accumulated un-decomposed or unbroken, consequently tying up of nutrients such as N making them unavailable to plants.

### Table 2. Soil fertility data for the selected ERPP Irrigation schemes in Pemba Island (topsoil samples 0 – 30 cm depth).

| MU               | Texture | pH (H\(_2\)O) | EC dS.m\(^{-1}\) | OC g.kg\(^{-1}\) | OM | TN | F-Statistics |
|------------------|---------|--------------|-----------------|-----------------|----|----|--------------|
| PEMBA            |         |              |                 |                 |    |    |              |
| Dobi Irrigation Scheme |      |              |                 |                 |    |    |              |
| DO-Val           | SCL     | 6.3a         | 0.5b            | 10.8b           | 18.5b | 0.2c |              |
| DO-Val2          | SC      | 5.7b         | 0.06a           | 11.0b           | 18.9b | 0.7a |              |
| DO-Hi1           | SCL     | 5.4c         | 0.06a           | 11.6a           | 19.9a | 0.4b |              |
| One Way ANOVA (F-Statistics) |        | 46.6***      | 77.3***         | 10.5*           | 10.7** | 2065.**** |              |
| CV (%)           |         |              |                 |                 |    |    |              |
| Kwalempona Irrigation Scheme |     |              |                 |                 |    |    |              |
| KWA-Val          | C       | 6.0b         | 0.08b           | 21.2a           | 36.4a | 0.6a |              |
| KWA-Val2         | C       | 6.9a         | 0.12a           | 16.0b           | 27.4b | 0.5b |              |
| KWA-Hi1          | SCL     | 5.9b         | 0.04c           | 16.3b           | 28.1b | 0.6a |              |
| One Way ANOVA (F-Statistics) |     | 57.6***      | 1607.1***       | 197.5***        | 196.8*** | 77.3*** |              |
| CV (%)           |         |              |                 |                 |    |    |              |
| Kwalempona Irrigation Scheme |     |              |                 |                 |    |    |              |
| MA-Val           | C       | 5.1b         | 0.11c           | 19.7b           | 33.9b | 0.7b |              |
| MA-Val2          | SCL     | 5.7a         | 0.03b           | 20.5b           | 35.3b | 0.8a |              |
| MA-Hi1           | SCL     | 5.1b         | 0.06a           | 25.9a           | 44.6a | 0.8a |              |
| One Way ANOVA (F-Statistics) |     | 31.9***      | 2213.9***       | 173.0***        | 173.6*** | 42.4*** |              |
| CV (%)           |         |              |                 |                 |    |    |              |
| OLE Irrigation Scheme |     |              |                 |                 |    |    |              |
| OLE-Pa1          | C       | 5.9a         | 0.02b           | 16.1b           | 27.7b | 0.7b |              |
| OLE-Pa2          | SCL     | 5.4b         | 0.26a           | 24.9a           | 42.8a | 0.8a |              |
| One Way ANOVA (F-Statistics) |     | 29.31**      | 6352.941***     | 660.59***       | 657.94*** | 66.37** |              |
| CV (%)           |         |              |                 |                 |    |    |              |
3.2. Soil Organic Carbon (SOC) and Organic Matter (SOM)

Results of organic carbon (OC) determination from the top soil (0 - 30 cm) samples in ERPP irrigation schemes in Pemba and Unguja Isles ranged from 10.8 g kg\(^{-1}\) to 33.4 g kg\(^{-1}\). This corresponds to 18.5 g kg\(^{-1}\) to 57.4 g kg\(^{-1}\) SOM (Tables 2, 3, and 4). The data showed that % OC was high in 21%, medium in 63%, and low in 16% of the mapping units surveyed. In Pemba, Dobi MUs showed lowest % OC compared with Kwalempona and Ole irrigation schemes which had medium % OC. In Machigini irrigation scheme a third of the MUs (MA-Hi1) were rated as high % OC compared with the two thirds with medium values (MA-Va1 & Va2). Since SOM content was calculated from SOC [25], these parameters has similar trend. It is generally accepted that a threshold for SOM in most soils is 34 g kg\(^{-1}\) [44; 41; Tables 2, 3 and 4]. Determination of Organic carbon (OC) or Soil Organic Matter (SOM) in the soil is important because humified OM molecules may react with mineral colloids and contribute to the stabilization of soil aggregates. While SOM favours water retention capacity and adsorption of fulvic and humic compounds by Fe\(^{3+}\) and Al\(^{3+}\) oxide, it also prevents their crystallization hence decreasing fixation power with regards to phosphates at unfavourable pH values. SOM provides much of the CEC, thus improve the soil pH, SOM quality as well as microbial activities in the soil [44; 41; Tables 2, 3 and 4]. So, any activity envisaged to improve the soil pH, fertility as well as microbial activities can, consequently, lead to an increase in N in the soil [41]. The low to very low levels of N in the surveyed areas suggests

### Table 2. Continued.

| MU          | Texture | C/N | Pavg mg.kg\(^{-1}\) | CEC (cmol (+).kg\(^{-1}\)) | Ca | Mg | K | Na | BS (%) | ESP (%) |
|-------------|---------|-----|---------------------|-----------------------------|----|----|---|----|--------|---------|
| PEMBA       |         |     |                     |                             |    |    |   |    |        |         |
| Dobi Irrigation Scheme |         |     |                     |                             |    |    |   |    |        |         |
| DO-Va1      | SCL     | 43.0 | 5.9b                | 20.7c                       | 7.4b | 2.0c | 0.07b | 0.47b | 48.0b  | 2.3b    |
| DO-Va2      | SCL     | 15.0 | 5.6c                | 28.2b                       | 11.2a | 2.2b | 0.06c | 0.69a | 50.0a  | 2.4a    |
| One Way ANOVA (F-Statistics) |         |     |                     |                             |    |    |   |    |        |         |
| Rep         |         | 1445.3*** | 54.0***          | 239.5***                    | 652.5*** | 134.6*** | 2640.1*** | 1032.7*** | 329.6*** | 960.4*** |
| CV (%)      |         | 12   | 5                   | 10                           | 6   | 3   | 1   | 1   | 1      | 3       |
| Kwalempona Irrigation Scheme |         |     |                     |                             |    |    |   |    |        |         |
| KWA-Va1     | C       | 33.0 | 5.8b                | 57.5a                       | 24.6a | 3.3a | 0.17a | 0.60a | 50.0a  | 1.0c    |
| KWA-Va2     | C       | 31.0 | 5.6c                | 11.5c                       | 4.2c  | 0.9c  | 0.14b | 0.38b | 50.0a  | 3.3a    |
| KWA-Hi1     | SCL     | 28.0 | 6.2a                | 23.4b                       | 6.3b  | 2.2b  | 0.14b | 0.32c | 38.0b  | 1.4b    |
| One Way ANOVA (F-Statistics) |         |     |                     |                             |    |    |   |    |        |         |
| Rep         |         | 50.3*** | 3149.1***          | 3217.9***                   | 4276.3*** | 1963.4*** | 99.1*** | 805.9*** | 167.6*** | 2453.1*** |
| CV (%)      |         | 11   | 5                   | 13                           | 9    | 3   | 1   | 1   | 1      | 3       |
| Kwalempona Irrigation Scheme |         |     |                     |                             |    |    |   |    |        |         |
| MA-Va1      | C       | 27.0 | 6.1a                | 56.2a                       | 19.1a | 6.2a  | 0.29c | 0.68a | 47.0a  | 1.2b    |
| MA-Va2      | SCL     | 26.0 | 0.3c                | 21.6c                       | 5.4c  | 2.0c  | 0.33b | 0.60b | 38.0c  | 2.8a    |
| MA-Hi1      | SCL     | 34.0 | 2.8b                | 42.7b                       | 12.5b | 3.6b  | 0.50a | 0.38c | 40.0b  | 0.9c    |
| One Way ANOVA (F-Statistics) |         |     |                     |                             |    |    |   |    |        |         |
| Rep         |         | 166.0*** | 4218.5***          | 1255.9***                   | 1919.6*** | 1824.9*** | 631.5*** | 561.7*** | 95.7*** | 2326.6*** |
| CV (%)      |         | 11   | 4                   | 13                           | 8    | 4   | 1   | 2   | 1      | 3       |
| OLE Irrigation Scheme |         |     |                     |                             |    |    |   |    |        |         |
| OLE-Pa1     | C       | 23.0 | 9.6a                | 47.5a                       | 20.9a | 2.4a  | 0.44a | 0.37a | 51.0a  | 0.8a    |
| OLE-Pa2     | SCL     | 30a  | 6.8b                | 41.6b                       | 18.6b | 1.9b  | 0.22b | 0.33b | 51.0a  | 0.8a    |
| One Way ANOVA (F-Statistics) |         |     |                     |                             |    |    |   |    |        |         |
| Rep         |         | 257.1*** | 424.86***          | 65.48***                    | 50.60*** | 200.11*** | 1500.00*** | 48.82*** | 0.00ns  | 0.00ns  |
| CV (%)      |         | 10   | 6                   | 13                           | 9    | 3   | 1   | 1   | 1      | 4       |

*: significant at \(P=0.05\); **: significant at \(P=0.01\); ***: significant at \(P=0.001\); ns: not significantly different from each other; CV: Coefficient of variation. Values followed by dissimilar letters in the same column for each parameter are significantly different from each other at \(P=0.05\) according to Fischer Least significance difference (LSD). EC = Electrical Conductivity; TN = Total Nitrogen; C/N = Carbon/Nitrogen ratio; Pavg = Available Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; Na = Sodium; OC = Organic Carbon; CEC = Cation Exchange Capacity; BS = Base Saturation, ESP = Exchangeable Sodium Percentage; SCL = Sand Clay Loam; CL = Clay Loam; C = Clay; CH: Chipogolo; MSAG: Msagali; Pa: Plain; Pi: Piedmont.
application of ammoniacal form of N, which resists better to leaching caused by rainfall or irrigation as the case may be in the surveyed areas.

Table 3. Soil fertility data for the selected ERPP Irrigation schemes in Unguja Islands (topsoil samples 0 – 30 cm depth).

| UNGUA | Bandanajahi Irrigation Scheme | BM-Pa1 SC 6.8a 0.13a 20.1a 34.6a 0.9a 24.0c 6.1a 15.4b 5.8b 1.2b 0.34b 0.39c 50.0b 2.5b | BM-Pa2 SCL 5.9c 0.07c 18.3b 31.6b 0.4c 49.0a 3.0b 40.0a 15.9a 1.2b 0.10c 1.08a 46.0c 2.7a | BM-Pa3 SCL 6.2b 0.09b 13.7c 23.5c 0.5b 26.0b 0.7c 41.2a 15.6a 4.8a 0.44a 0.58b 52.0a 1.4c |
|       | One Way ANOVA (F-Statistics) | Rep 39.5** 702.3*** 264.5** 270.0** 1291.0* 1188.8* 3538.0* 1349.8* 1402.4* 3750.0* 2152.3** 1727.1* 287*** 711.3** | CV (%) 5 1 8 11 2 12 4 12 8 4 | Mchangani Irrigation Scheme | Rep 0.2a 12 32.9a 33.4a 57.4a 1.4b 24.0a 7.1a 23.5b 9.0b 1.4b 0.14b 0.6a 48.0a 2.6a | CV (%) 5 1 8 11 2 12 4 12 8 4 | MCH-Pa2 SCL 5.0b 0.1b 32.9a 56.6a 1.6a 21.0b 6.2b 71.8a 31.1a 3.0a 0.23a 0.3b 48.0a 2.6b | CV (%) 2 3 66.4** 0.7ns 6.2b 0.4c 24.0a 7.1a 23.5b 9.0b 1.4b 0.14b 0.6a 48.0a 2.6a | MCH-Pa2 SCL 5.0b 0.1b 32.9a 56.6a 1.6a 21.0b 6.2b 71.8a 31.1a 3.0a 0.23a 0.3b 48.0a 2.6b | CV (%) 2 3 66.4** 0.7ns 6.2b 0.4c 24.0a 7.1a 23.5b 9.0b 1.4b 0.14b 0.6a 48.0a 2.6a |
|       | One Way ANOVA (F-Statistics) | Rep 33.9** 1500.0** 0.9ns 0.7ns 66.4** 66.4** 68.4** 3065.6** 3494.6** 1751.8* 837.9*** 1329.3* 0.00ns 5245.7* | CV (%) 5 1 12 15 2 10 5 15 10 3 1 1 1 4 3 |

*: significant at P = 0.05; **: significant at P = 0.01; ***: significant at P = 0.001; ns: not significantly different from each other; CV: Coefficient of variation. Values followed by dissimilar letters in the same column for each parameter are significantly different from each other at P = 0.05 according to Fischer Least significance difference (LSD). EC = Electrical Conductivity, TN = Total Nitrogen; C/N = Carbon/Nitrogen ratio; Pav = Available Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; Na = Sodium; OC = Organic Carbon; CEC = Cation Exchange Capacity; BS = Base Saturation, ESP = Exchangeable Sodium Percentage; SCL = Sand Clay Loam; CL = Clay Loam; C = Clay; CH: Chipogolo; MSAG: Msagali; Pa: Plain; Pi: Piedmont.

3.4. C/N Ratio

As far as humification is concerned, an average C/N ratio of 10 (i.e. 8 - 13) is considered as optimal [36]. The C: N ratio of most of the surveyed areas range from 15 – 49 in ERPP irrigation schemes in Pemba and Unguja Islands (Table 2) and was rated as poor quality in 89% and moderate quality SOM in 11% of MUs (Table 4). It is generally accepted that C/N ratios between 8 and 12 are considered to be the most favourable, implying a relatively fast mineralisation of N from the organic materials. Results show that all the mapping units had C/N ratio outside the suggested range. The observed C/N ratio in the mapping units suggests suboptimal condition for plant growth. This calls for SOM management in all the irrigation schemes

3.5. Available Phosphorus (AP)

Phosphorus (P) is an essential macro element for plant growth, hence an important soil fertility indicator. In agriculture, management of P is second only to management of N in its importance for the production of healthy and profitable crop yields. Results show that of all the top soil samples taken from the MUs in ERPP irrigation schemes in Pemba and Unguja Islands (Tables 2, 3 and 4), 84% has low P and 16% has medium levels of available P. The data showed that the available P range from 0.3 – 9.6 mg kg⁻¹ top soils (Tables 2, 3). An average P level of 7 mg kg⁻¹ is considered optimal below which P deficiency symptoms are likely to occur in most crops. Based on the generally accepted threshold level of P, 84% of the surveyed MUs has P values below the critical range and will need serious fertilizer management program. The medium P availability manifested in 16% of all the mapping units in the areas suggests that P in these areas is moderately sufficient and may need frequent maintenance for sustainable irrigated agricultural development.

3.6. Exchangeable Bases (K, Mg, Ca)

Results of the exchangeable bases (Ca, Mg and K) in the top soils of the MUs surveyed are presented in Tables 2, 3 and 4. These results indicate that whereas the levels of exchangeable Ca and Mg were generally medium or high to very high, K levels was rated as very low/low or medium

3.6.1. Exchangeable Calcium

Exchangeable Ca²⁺ in the topsoil of the ERPP irrigation schemes ranged from 4.2 cmol (+) kg⁻¹ – 31.1 cmol (+) kg⁻¹ rated as high in 11% and very high in 89% of the MUs surveyed [45] proposed that in most of the crops, the recommended threshold level of Ca²⁺ is 5 cmol (+) kg⁻¹. It is generally acknowledged that field conditions that limit Ca²⁺ uptake produce lower crop yields than crops grown with adequate Ca²⁺ [46]. Based on the critical limits, with the exception of KWA-Va2 in Kwalenpona irrigation scheme, Ca²⁺ is not limiting in the rest of the surveyed MUs as the values lies above the proposed critical limits.

3.6.2. Exchangeable Magnesium

Exchangeable Mg²⁺ range from 0.9 cmol (+) kg⁻¹ – 6.2 cmol (+) kg⁻¹. This was rated as medium in 42%, high in 47% and very high in 11% of the study MUs. The recommended value of Mg²⁺ in most crops is 2 cmol (+) kg⁻¹ [47]. These data suggests that 56% of all the surveyed MUs in ERPP irrigation schemes in Pemba and Unguja have sufficient Mg²⁺ supplies for crop growth whereas the other 31% have insufficient Mg.
3.6.3. Exchangeable Potassium

Potassium (K) in the surveyed area range from 0.06 cmol (+) kg\(^{-1}\) to 0.52 cmol (+) kg\(^{-1}\) rated as very low in 16%, low in 26% and medium in 58% of the studied MUs. In general terms, a response to K fertilizers is likely when a soil has an exchangeable K value of < 0.2 cmol (+) kg\(^{-1}\) soil and unlikely when it is above 0.4 cmol (+) kg\(^{-1}\) soil [36; 48]. In this survey, 42% are likely to respond to K fertilizers, 28% are unlikely whereas 46% will somewhat respond to K fertilizers since they are in between. The data shows that there are sufficient levels of K in 28% of the MUs surveyed in the ERPP irrigation schemes in Pemba and Unguja, and so, K is unlikely to respond if applied.

### 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 | % OC | CEC | ESP | C/N  |
|--------------|------|-----------------------------|---------------------------|-------|--------------|-----------------------|------|-----|-----|------|
| Pemba        | Pa   |                             |                           |       |              |                        |      |     |     |      |
| Dobi         | DB-MP2 | Va11 | Almost flat                | <2    | MA           | VL                    | L    | M   | M   | NS   | PQ   |
|              | DB-P1  | Va12 | Almost flat                | <1    | MA           | VL                    | L    | M   | L   | NS   | MQ   |
|              | BM-MP1 | Hi1  | Sloping                    | <2    | SA           | VL                    | L    | M   | H   | NS   | PQ   |
| Kwalemona    | KWA-MP2 | Va1  | Almost flat                | <2    | MA           | VL                    | L    | M   | VH  | M    | NS   | PQ   |
|              | KWA-MP3 | Va2  | Almost flat                | <2    | N            | VL                    | L    | LH  | M   | M    | NS   | PQ   |
|              | KWA-MP1 | Hi1  | Sloping                    | 2-3   | MA           | VL                    | L    | V       | M | H       | M | NS   | PQ   |
| Machigini    | MA-P1  | Va1  | Almost flat                | <2    | SA           | VL                    | M    | VH  | M   | M    | NS   | PQ   |
|              | MA-MP2 | Va2  | Almost flat                | <2    | MA           | VL                    | L    | M   | M   | M    | NS   | PQ   |
|              | MA-MP1 | Hi1  | Sloping                    | 2-3   | SA           | VL                    | L    | VH  | M   | H    | NS   | PQ   |
| Ole          | OLE-P1 | Pa1  | Almost flat                | 0-1   | MA           | VL                    | L    | M   | M   | VH   | M    | NS   | PQ   |
|              | OLE-MP1 | Pa2  | Almost flat                | 0-1   | SA           | VL                    | L    | M   | M   | VH   | M    | NS   | PQ   |
| Unguja       | Pa    |                             |                           |       |              |                        |      |     |     |      |
| K/Mzungu     | KBM-P1 | Pa2  | Almost flat                | <2    | MA           | VL                    | L    | M   | VH  | M   | H    | NS   | PQ   |
| Bandamaji    | BM-P1  | Pa1  | Almost flat                | <2    | N            | VL                    | L    | VH  | M   | M   | M    | NS   | PQ   |
|              | BM-MP2 | Pa2  | Almost flat                | <2    | MA           | VL                    | L    | M   | VH  | M   | H    | NS   | PQ   |
| Koani        | KN-P1  | Pa1  | Almost flat                | <2    | SLA          | VL                    | M    | VH  | M   | M    | VH   | NS   | PQ   |
| Mchangani    | MCH-P1 | Pa1  | Almost flat                | <2    | SA           | L                     | M    | VH  | M   | M    | VH   | NS   | PQ   |
|              | MCH-P2 | Pa1  | Almost flat                | <2    | VSA          | L                     | M    | VH  | M   | M    | VH   | NS   | PQ   |
| Mtwango      | MTW-P2 | Pa1  | Almost flat                | <2    | MA           | VL                    | L    | M   | VH  | M   | M    | NS   | PQ   |

Classification: According to NSS (1990) guidelines. Pa = Plain; Pi = Piedmont; S (%) = Slope per cent; S = Slope, N = Nitrogen, P = Phosphorus, K = Potassium, Ca = Calcium, Mg = Magnesium, %OC = Per cent organic carbon, CEC = Cation exchange capacity, ESP = Exchangeable sodium percentage, C/N = Carbon to Nitrogen ratio: (Based on Mlingano National Soil Service (NSS, 1990) Laboratory guide to general soil fertility evaluation); VL = Very low; L = Low; M = Medium; H = High; VH = Very high; NS = Non Sodic; PQ = Poor quality; MQ = Moderate quality; N = Neutral soil reaction; SA = Strong acid; VSA = Very strongly acid, MA = Medium acid, SLA = Slightly acid

3.7. Cation Exchange Capacity

Cation exchange capacity (CEC) is the capacity of a soil for ion exchange of positively charged ions between the soil and the soil solution. Cation exchange capacity is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination [49]. The higher the CEC, the more capable the soil is to retain nutrients. High CEC means more nutrients are held on the soil, decreasing their mobility and uptake whereas low CEC means that more nutrients are in the soil solution, making them available to plants but also increasing the likelihood of leaching. Studies have shown that soils with CEC values of between 6 - 12 cmol (+) kg\(^{-1}\) soil are poor in exchangeable bases [37]. Cation exchange capacity values in most topsoil in the ERPP irrigation schemes in Pemba and Unguja was rated as medium, high to very high (Tables 2, 3 and 4). In all, these values range between 11.5 cmol (+) kg\(^{-1}\) - 71.8 cmol (+) kg\(^{-1}\), and were rated as medium in 32%, high in 16% and very high in 53% of the MUs surveyed. The medium to very high CEC could be related to the clay mineral and SOM or OC present in these soils. However, it is recommended to apply both manure/compost manure and the required amount of fertilizer so as to increase the humus content of the soil and consequently, higher or maintenance of higher CEC, thus, better nutrients retention.

3.8. Exchangeable Sodium (Na) or Exchangeable Sodium Percentage (ESP)

Tables 2, 3 and 4, presents the levels of topsoil exchangeable Na and or exchangeable sodium percentage (ESP) as well as the electrical conductivity (EC) in the ERPP irrigation schemes in Pemba and Unguja surveyed MUs. The results of Na\(_{exch}\) indicates that the levels of Na\(^+\) in the top soils corresponds to 0.23 – 1.08 cmol (+) kg\(^{-1}\) soil in the surveyed MUs. These values were rated as low in 5.5%, medium in 89% and high in 5.5% of the surveyed MUs. The corresponding ESP range from 0.4 – 3.3%. These were rated as non-sodic. The critical values of ESP above which most crops are affected are established at 15% [50]. These results suggest that the surveyed areas have no threat to sodicity problems.
3.9. Cation Ratios

The availability of nutrients for uptake by plants depends not only upon absolute levels but also on relative amounts of individual elements. The Ca/Mg and Mg/K ratios indicate if there are imbalances among these nutrients. For example, if the Ca/Mg ratio is high, the Ca will reduce plant uptake of Mg even if there is enough Mg in the soil. However, if the ratio is good, but the total amounts of both nutrients are low, they must be applied. It was suggested by some soil chemists working in tropical areas that the optimal cation ratio for the growth of most crops is assumed to be equal to 76/18/6 for Ca/Mg/K respectively (12.7/3/1). Although the general trend doesn’t indicate a good balance, more importantly are the individual nutrient ratios i.e. Ca/Mg; Mg/K; K/TEB.

Research has indicated that the Ca/Mg ratios of 3 – 5 in the topsoil are considered optimal for most crops. Results of nutrient balance in ERPP irrigation schemes in Pemba and Unguja top soils are shown in Table 5. The data show that Ca/Mg ratios ranged from 2.3 – 12.9, Mg/K from 3.4 – 37.2 and K/TEB ratio from 0.4 – 5.1%. It was observed that Ca/Mg ratio in 58% of the MUs is optimal for most crops and 42% are un-optimal. The optimal range of Mg/K ratio is between 1 – 4 for most crops [36]. According to the suggested range, the K/Mg ratio is sub optimal. The K/TEB is measure of K deficiency. When this ratio is greater than 2 suggests no K problems and when less than 2 suggests K deficiency problems. Results show that 58% of the surveyed MUs has K/TEB ratio < 2% suggesting K problems and application of K is likely to respond. However, 42% of the surveyed mapping units have K/TEB ratio greater than 2% suggesting that problems of K – deficiency is unlikely.

Table 5. Summary of results with emphasis on the nutrient balance in ERPP Irrigation schemes in Pemba and Unguja Islands (0 – 30 cm).

| Mapping Unit       | Texture | Ca/Mg | Mg/K | K/TEB | TEB |
|--------------------|---------|-------|------|-------|-----|
| Dobi Irrigation Scheme |         |       |      |       |     |
| D-Va11             | SCL     | 3.6b  | 28.7b| 0.7b  | 10.0b|
| D-Va12             | SC      | 5.1a  | 37.2a| 0.4c  | 14.2a|
| D-Hi1              | SCL     | 2.4c  | 13.7c| 2.0a  | 9.6b |
| One Way ANOVA (F-Statistics) |     |       |      |       |     |
|                      | F Value | 920.5*** | 1330.0*** | 3500.0*** | 371.0*** |
|                      | CV (%)   | 4      | 11   | 2     | 7    |
| Kwalempona          |         |       |      |       |     |
| KWA-Va1            | C       | 7.6a  | 18.7a| 0.6c  | 28.6a|
| KWA-Va2            | C       | 4.5b  | 6.6c | 2.5a  | 5.7c |
| KWA-Hi1            | SCL     | 2.9c  | 15.2b| 1.6b  | 9.0b |
| One Way ANOVA (F-Statistics) |     |       |      |       |     |
|                      | F Value | 1486.6*** | 1397.3*** | 2216.5*** | 3701.7*** |
|                      | CV (%)   | 5      | 8    | 3     | 9    |
| Machigini Irrigation Scheme |         |       |      |       |     |
| MA-Va1             | C       | 3.1b  | 21.1a| 1.1c  | 26.3a|
| MA-Va2             | SCL     | 2.7c  | 6.0c | 4.0a  | 8.3c |
| MA-Hi1             | SCL     | 3.5a  | 7.2b | 3.0b  | 17.0b|
| One Way ANOVA (F-Statistics) |     |       |      |       |     |
|                      | F Value | 123.5*** | 2973.4*** | 1862.8*** | 1737.1*** |
|                      | CV (%)   | 4      | 8    | 4     | 9    |
| Ole Irrigation scheme |         |       |      |       |     |
| O-Pa1              | C       | 8.6b  | 5.5b | 1.8a  | 24.1a|
| O-Pa2              | SCL     | 9.6a  | 8.6a | 1.1b  | 21.1b|
| One Way ANOVA (F-Statistics) |     |       |      |       |     |
|                      | F-Value | 45.2** | 691.6*** | 825.8*** | 65.8** |
|                      | CV (%)   | 6      | 5    | 2     | 10   |
| UNGUJA             |         |       |      |       |     |
| Bandamaji Irrigation scheme |         |       |      |       |     |
| BM-Pa1             | SCL     | 4.9b  | 3.4c | 4.5a  | 7.7c |
| BM-Pa2             | SCL     | 12.9a | 11.7a| 0.6c  | 18.3b|
| BM-Pa3             | SCL     | 3.3c  | 10.8b| 2.1b  | 21.4a|
| One Way ANOVA (F-Statistics) |     |       |      |       |     |
|                      | F-Value | 2953.1*** | 1760.6*** | 3480.2*** | 1362.7*** |
|                      | CV (%)   | 6      | 6    | 4     | 8    |
| Mchangani Irrigation scheme |         |       |      |       |     |
| MCH-Pa1            | SCL     | 6.2b  | 0.0b | 1.3a  | 11.2b|
| MCH-Pa2            | CL      | 10.3a | 12.8a| 0.7b  | 34.6a|
| One Way ANOVA (F-Statistics) |     |       |      |       |     |
|                      | F-Value | 852.44*** | 4500.0*** | 1238.5*** | 3105.0*** |
|                      | CV (%)   | 6      | 8    | 2     | 10   |

***: significant at \( P = .001 \); CV: Coefficient of variation. Values followed by dissimilar letters in the same column for each parameter are significantly different from each other at \( P = .05 \) according to Fischer Least significance difference (LSD). K = Potassium; Ca = Calcium; Mg = Magnesium; Na = Sodium, TEB = Total Exchangeable Bases, BS = Base Saturation; SCL = Sand Clay Loam; SL = Sand loam; CL = Clay Loam; C = Clay.
4. Conclusion

In conclusion, the results of the present study provide soil fertility status in the selected ERPP irrigation schemes. Data also suggest that soil chemical indicators such as pH, TN, P and OM are the major soil fertility constraints to crop production in the area followed by CEC. This information could be incorporated in the soil fertility management in Tanzania, thus, contributing significantly in the efficient utilisation of land resources in the study areas.

Conflict of Interest

All the authors do not have any possible conflicts of interest.

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