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Assessment of Soil Chemical Properties and Fertility in Some Traditional Irrigation Schemes of the Babati District, Manyara Region, Tanzania

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Abstract: *Aim:* To assess the soil chemical properties and fertility status in selected traditional irrigation schemes in Babati District Council in Manyara Region, Tanzania. *Place and Duration of Study:* The survey was conducted in Mkombozi, Muungano and Endamajek proposed irrigation schemes, Babati District, in Tanzania during the dry season of 2002. *Methodology:* Soil sampling was done after the soils were grouped into similar soil types following pedogeomorphic approach whereby eleven (11) mapping units were delineated but only ten (10) mapping units were sampled. Using zigzag sampling techniques, thirty (30) disturbed soil samples were collected at depth 0 – 30 cm from the delineated pedogeomorphic units. The soil samples were bulked thoroughly mixed and sub sampled to obtain a representative composite sample and sent for laboratory analysis at the Selian Agricultural Research Institute (SARI), Arusha, Tanzania. *Results:* The results showed significant difference in the fertility status in the selected sites of each scheme. Based on guidelines of soil nutrient contents established elsewhere, pH of the soils in the study areas were rated as mildly alkaline in 2% in Endamajek and moderately alkaline in 80% in Muungano, 29% in Mkombozi and 73% in Endamajek. The soils were also rated as strongly alkaline in 66% of the area in Mkombozi. Crop production was moderately constrained by sodicity and strongly sodic in 26.6% of the total surveyed area in Endamajek. TN and OM were low, in Muungano; very low or low to medium,; in Mkombozi and low to medium, in Endamajek respectively. Available P was rated as low in 74% and high in 26% of the area in Muungano; high in Mkombozi as well as medium in Endamajek. Of the total surveyed area, 66% in Mkombozi and 26.6% in Endamajek have low CEC. C/N ratio in 46% of the total area surveyed in Muungano was of good quality suggesting ideal conditions for plant growth as compared with Mkombozi and Endamajek. Results also indicated that Ca: Mg ratios to be less than suggested guidelines in 35% of the surveyed areas in Muungano and all the surveyed areas in Endamajek suggesting that plants would probably respond to the addition of Ca or Mg in such areas. *Conclusion:* The soil fertility status and overall information from this study could be used in fertilizer and sodicity and/or salinity management studies to establish nutrient and drainage requirements for different crops which are grown in these areas.

Keywords: Calcium, Cation Exchange Capacity, Crop Production, Sodicity, Fertility Constraints, Management Practices, Soil Organic Matter, Survey

1. Introduction

About 90% of the population in Babati District Council (BDC), Manyara Region, who lives in the rural areas and practise agro-pastoralism for their livelihood have realized that sound profit margins can also be achieved through crop diversification including rice (*Oryza sativa* L.), maize (*Zea mays* L) and oil seed crops cultivation. However, cultivation of most of these crops is rainfed and takes place during the long rainy season (Masika). For example in 2012, it was reported that in Manyara Region, about 518,897 ha was put under cultivation during wet season (Masika) as opposed to 11,175 ha (2.2%) during the short rains (Vuli). Babati District Council (BDC) has an irrigation potential of 15,988 ha out of which 37% is under irrigation through different water sources. 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 District Council. Assured availability of water for irrigation during growth of various crops including paddy will contribute significantly to the economic growth, not only for the people of BDC and Manyara Region, but also will contribute to the overall National Economic Growth. The most commonly grown crops in the District are: maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L), pearl millet (*Pennisetum glaucum*), rice (*Oryza sativa* L.), beans (*Phaseolus vulgaris* L), cowpea (*Vigna unguiculata* L.), groundnuts (*Arachis hypogea* L.), sunflowers (*Helianthus annuus*), sweet potatoes (*Ipomoea batatas*), cassava (*Manihot esculenta*), and onions (*Allium cepa* L.). However, farmers in the area have shown interest in paddy cultivation if water availability for irrigation is ensured with a view to address food security within and outside the region as well as economic challenges. Since irrigation development is an expensive undertaking, detailed evaluation particularly on the fertility status of the areas to be developed was necessary. This is because nutrients and nutrients balance is of great challenge in most areas of the district just as in similar environments in the tropics [1, 2]. Common soil fertility challenges in most areas in the tropics include excessive leaching, chemical degradation, nutrient mining and salinity, decline in soil organic matter and high prices of fertilisers [1, 3, 4].

Due to these challenges and other complex soil, crop management, farming systems and soil fertility [5] the average yield of paddy in the study area is 1.6 t ha^{-1} which is very low compared with a potential of 8 t ha^{-1} [1, 6, 16]. Although no studies have been conducted on the assessment of soil chemical properties and fertility in Endamajek, Muungano and Mkombozi proposed schemes for irrigation development, experience from studies of similar environments elsewhere in Africa have shown soil fertility decline [4, 7, 8, 9] often leading to low crop production and productivity [10, 11, 12, 13] as may be the case with soils in Babati District Council. 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 [14, 15] as are realistic in predicting plant growth and development. Assessment and understanding of the soil fertility status based on the attributes described in [14, 15] will not only enhance strategies for soil fertility management and land development, but also will provide input into the design and planning of crop nutrition packages

in the study areas. To date, studies on soil fertility status in Tanzania are very scarce [2, 9, 18]. The objective of this study was therefore to assess the soil chemical properties and fertility status in the selected irrigation schemes of Babati District, Manyara Region, Tanzania.

2. Material and Methods

2.1. Description of Study Area

The irrigation schemes of Mkombozi, Muungano and Endamajek each with 250 ha are located in Babati District, Manyara Region, Tanzania. Mkombozi irrigation scheme is located at 4°01'60"S and 35°45' 57"E, about 36 km NW of Babati town at about 1,341m above mean sea level. Muungano irrigation scheme is between Mawemairo and Matufa villages about 21 km NE of Babati town dissected by the main road from Arusha to Babati. The Endamajek irrigation scheme is located at 4°18'00"S and 35°52' 00"E, 25 km East of Babati town at an altitude of 1,524 m a.m.s.l.

These irrigation schemes are generally found on a plain landscape. The climate of the three irrigation schemes is characterised as semi-arid [19]. Rainfall distribution in Mkombozi and Muungano irrigation schemes is fairly bimodal with most of the rains (42.8%) falling in March through April (24.2% in April alone) and about 24.4% in November through December (Table 1, Fig 1). According to these data, about 761.1mm of rainfall annually is possible at an altitude of 1,341m above mean sea level. Mean annual temperature for Mkombozi and Muungano irrigation schemes is 23.8°C. June and July are the coldest months, while the warmest months are October up until January. The annual evapotranspiration is about 2,610 mm. Moisture surplus exists between March and April. Humidity Index (HI) shows that April, May and November are humid months (HI > 1.00) (Fig 2). Table (1) shows the summary of the climatic variables as depicted from Magugu TPRI meteorological station. For Endamajek (Qash) irrigation scheme, climate variables from Gallapo mission rainfall data with Lat. 4º18"00S; Long. 35º52"00E Alt. 1,524 m m.a.s.l was used. Rainfall distribution in *Qash* scheme is fairly bimodal with most of the rains (62%) falling in January through April (18.9% in April alone) and about 28.3% if present in November through December (Table 1). According to these data, about 845 mm of rainfall annually is possible at an altitude of 1,524 m above mean sea level.

Table 1. Climatic data representative for Mkombozi, Mawemairo/Matufa and Endamajek irrigation schemes.

	J	F	M	A	M	J	J	A	S	O	N	D
Tmax (°C)	31.1	24.9	30.7	28.5	26.9	27	26.9	28.4	29.9	31.8	31.5	31.5
Tmin (°C)	18.6	19.2	20	19.5	18.7	16.4	16.2	17	18.1	19.3	19.9	19.5
Tmean (°C)	24.8	22	25.3	24	22.8	21.7	21.5	22.7	24	25.5	25.7	25.5
RH (%)	74.6	74	76.3	77.6	77.2	72.9	71.7	67.8	67.1	65.3	68.4	71.8
ETo (mm/d)	8.9	7.9	7.5	7.1	6.3	6.5	5.3	6.8	6.9	8.1	7.7	7.9
ETo (mm/m)	268	236	226	212	190	196	159	204	208	242	232	237
0.5ETo(mm/m)	134	118	113	106	95	98	79.5	102	104	121	116	118.5
E-Pan A (mm/d)	11.2	6.7	6.4	7	5.5	5.7	7.7	10	11.7	8	9.7	8.6
E-Pan A (mm/m)	337	200	192.3	209.3	166	171	229.6	299.4	350.4	240	292	257

	J	F	M	A	M	J	J	A	S	O	N	D
Wind (mil/d)	83.4	80.4	90.8	87.1	85.2	74.8	86.6	78.7	88.4	96	91.1	100.1
R(mm) (Gallapo mission)	110	111	143	160	63	7	1	0	2	9	84	155
R(mm) (TPRI Magugu)	97.8	85	141.3	184.3	45.9	4.5	0.2	1	3.3	12.3	73.1	112.5

Source: Magugu and Gallapo Station, ETo = Potential evapotranspiration, RH = Relative humidity, SSR = Solar Radiation, SH = Sunshine hours
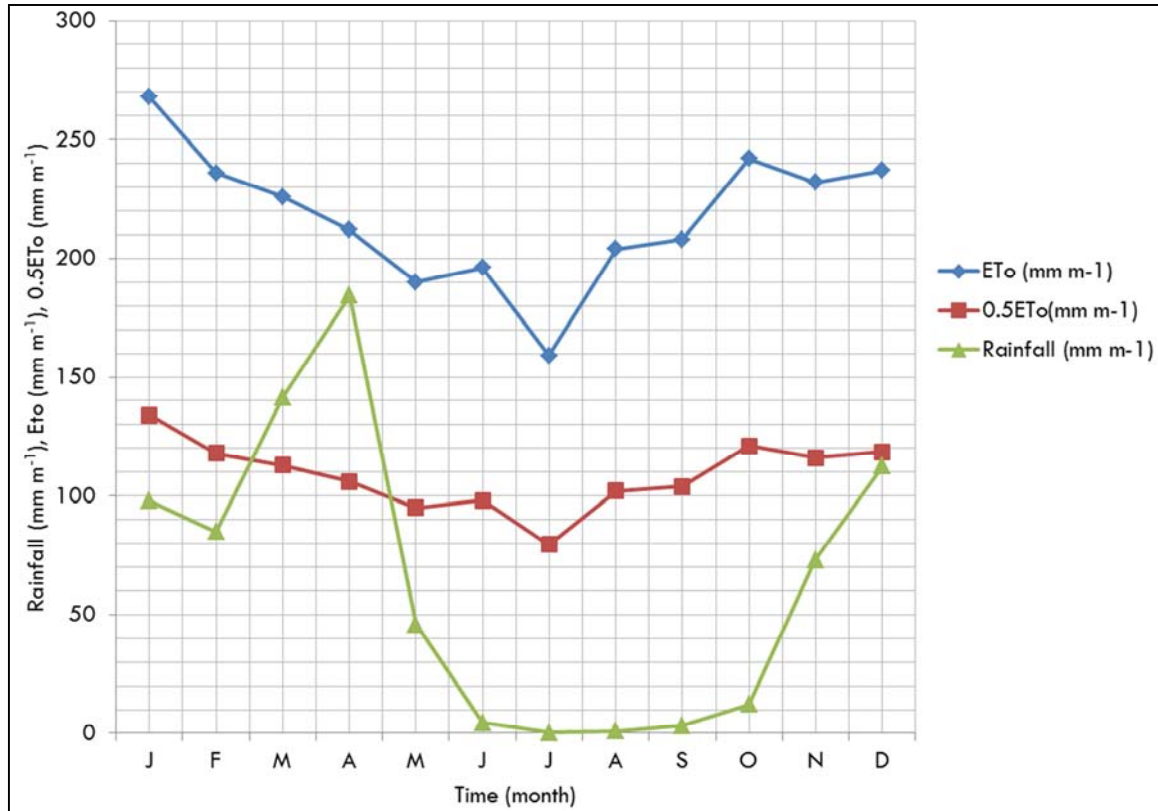

Figure 1. *Water balance and the determination of the growing period for the selected schemes.*
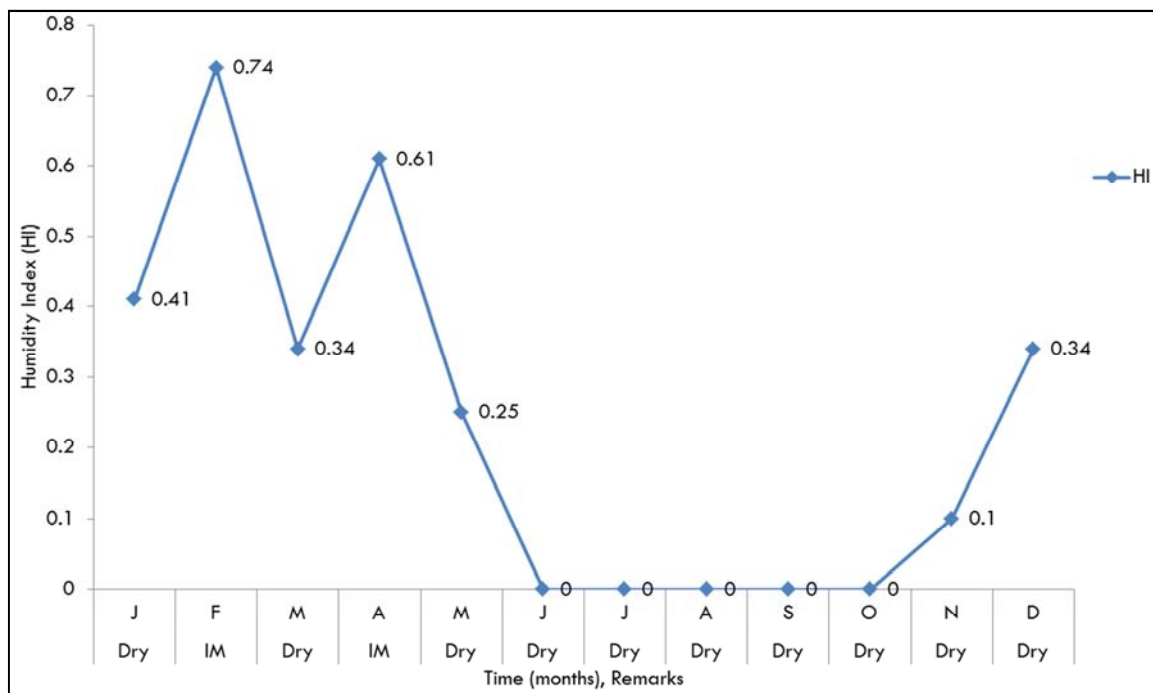

Figure 2. *Humidity index (HI) for the selected sites of Babati District, Manyara Region, Tanzania.*

2.2. Soil Sampling

Soil sampling in the Muungano, Endamajek and Mkombozi target areas was done after the soils were grouped into similar soil types or pedons following pedogeomorphic approach [20] whereby eleven (11) mapping units were delineated but only 10 mapping units were sampled. Of the eleven (11) mapping units, eight (8) were from Muungano and Endamajek (Qash) irrigation schemes i.e. four (4) mapping units each, and three (3) from Mkombozi (Gichameda) irrigation scheme. Using zigzag sampling techniques, thirty (30) 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 and 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 Selian Agricultural Research Institute (SARI), Arusha, 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 [21] and textural classes were determined using the USDA textural class triangle [17]. Organic carbon was determined by the Walkley and Black wet oxidation method [22] and OC was converted to organic matter (OM) by multiplying by a factor of 1.724 [23]. Soil reaction was measured potentiometrically in water and 1N KCl at a ratio of 1: 2.5 soils: water and KCl [24]. Total nitrogen was determined using micro-Kjeldahl digestion-distillation method [25].

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 (NH_4OAc) at pH 7, ethanol and acidified 1MKCl in the first percolate [26]. The absorbed NH_4^+ 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 [27] was followed. Determination of K and Na was done with flame photometer, Ca and Mg by Inductively Coupled Plasma Atomic Absorption Emission Spectrophotometer [28]. Cation exchange capacity (CEC) was done following the method by [28]. Potentiometric method was used to determine electrical conductivity (EC) of soil samples following the procedure described by [29]. 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 [30] by reacting with ammonium molybdate using ascorbic acid as a reductant in the presence of antimony, as in [31]. 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 [32]. 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.

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 (StatSoft Inc., Tulsa, OK, USA). 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 Table (2) which represent Muungano irrigation scheme, showed that pH of the top soils ranged from 7.1 to 7.8. These were rated as neutral to mildly alkaline. In Mkombozi scheme, soil pH of the top soils ranged from 8.4 to 8.8 in the top soil that rated as moderately alkaline to strongly alkaline. Regarding Endamajek (Qash) irrigation scheme, pH ranged from 7.5 to 8.0 in the top soils that rated as mildly alkaline to moderately alkaline. Soil pH is an important indicator in assessing soil fertility and its environment. For example, the normal pH range for optimal mineral elements availability for most crops is 6.0 to 7.5 [34; 35]. However, the soil in the studied areas (Mkombozi and Endamajek) were rated as moderately to strongly alkaline (Table 2, 3) [33] suggesting that mineral elements deficiency such as P, Ca, Fe, Cu, Zn, Mn and Mo are likely to occur [36; 37; 38]. Furthermore, unfavourable plant growth conditions such as severe root damage, shallow rooting, poor root development, susceptibility to drought and poor use of subsoil mineral elements have been reported in such pH range [39, 40]. Collectively, the constraints associated with alkaline conditions may threaten the yield potential particularly in all the study areas. In order to reverse this trend, soil pH has to be reduced to the acceptable range by acidification using different options. For example, adding elemental S to the soil will undergo chemical reaction with H_2O and O_2 to form sulfuric acid (H_2SO_4) in the presence of sulfur-oxidizing bacteria which eventually plays the role of reducing the soil pH. Likewise, addition of Fe and Al compounds in the soil reacts with H_2O to release H^+ ion which lowers pH. When soil microbes decompose plant materials or when humus is decomposed, carbonic acid (H_2CO_3) and organic acids are released which lowers the soil pH. Soil pH is similarly lowered after $(NH_4)_2SO_4$ is nitrified into NO_3^- and H^+ ions by soil bacteria.

Table 2. *Soil fertility data for the selected sites of Babati (topsoil samples 0–30 cm depth).*

Sample No.	Texture	pH (H$_2$O)	EC (dS. m^{-1})	OC (%)	TN	C/N	Avail. P (mg. kg^{-1})
MUUNGANO (MAWEMAIRO/MATUFA)							
Mu-P1	CL	7.10b	0.05d	1.08c	0.10a	11c	3.03b
Mu-P2	SCL	7.80a	0.14c	0.85d	0.05b	17a	1.47c
Mu-P3	SCL	7.60ab	0.17b	1.18b	0.10a	12bc	23.72a
Mu-P4	C	7.40ab	0.23a	1.25a	0.10a	13b	1.70c
One Way ANOVA (F-Statistics)							
F-Value	F-Value	2.6*	332.2***	48.9***	4.9*	53.5***	5465.7***
CV (%)		4.3	4.8	4.0	22.5	4.7	3.4
MKOMBOZI							
M-P1	SL	8.8a	0.08b	0.4b	0.03b	13a	22.38b
M-P2	SL-SCL	8.4a	0.47a	1.91a	0.14a	14a	33.34a
One Way ANOVA (F-Statistics)							
F-Value		2.607ns	211.0***	290.8***	739.5***	5.9ns	127.4***
CV (%)		10.3	5.8	10.1	1.7	13.7	22.5
ENDAMAJEK (QASH)							
E-P1	C	7.9a	0.41b	1.52a	0.11a	13a	5.09c
E-P2	C	7.7a	0.05c	1.33b	0.10a	13a	7.35b
E-P3	C	8.0a	1.36a	1.44ab	0.10a	14a	7.19b
E-Hi2	SL- SCL	7.5a	0.08c	1.34b	0.10a	13a	9.86a
One Way ANOVA (F-Statistics)							
F-Value		1.0ns	887.5***	4.9*	2.9ns	1.7ns	79.9***
CV (%)		5.0	7.5	5.0	5.0	5.0	5.1

Table 2. *Continue.*

Sample No.	Texture	CEC (me.100 g^{-1})	EB (me.100 g^{-1} soil)				BS %	ESP
			Ca	Mg	K	Na		
MUUNGANO (MAWEMAIRO/MATUFA)								
Mu-P1	CL	15.18b	15.50b	2.70c	0.70c	0.64c	100a	4.2c
Mu-P2	SCL	16.37b	15.00b	4.20b	0.50d	0.79b	100a	4.8b
Mu-P3	SCL	15.47b	12.10c	2.60c	3.29a	0.60c	100a	3.9c
Mu-P4	C	26.78a	18.80a	10.40a	1.04b	1.58a	100a	5.9a
One Way ANOVA (F-Statistics)								
F-Value	F-Value	163.5***	50.6***	898.8***	2692.7***	446.6***	0.0ns	56.9***
CV (%)		4.1	4.4	4.3	3.1	4.2	4.3	4.3
MKOMBOZI								
M-P1	SL	11.31b	16.0a	0.7b	0.20b	1.23b	100a	10.9b
M-P2	SL-SCL	14.58a	17.4a	1.3a	0.86a	1.73a	100a	11.9a
One Way ANOVA (F-Statistics)								
F-Value		58.9**	7.5ns	252.7***	705.2***	98.3***	0.0ns	8.2*
CV (%)		14.5	15.3	4.6	4.2	5.1	36.1	12.7
ENDAMAJEK (QASH								
E-P1	C	29.76a	20.2a	13.3a	3.62c	1.55a	100a	5.2b
E-P2	C	18.45b	4.5b	3.8c	5.48a	0.45c	100a	2.4c
E-P3	C	27.78a	19.1a	11.0b	4.93b	1.58a	100a	5.7b
E-Hi2	SL- SCL	6.55c	4.1b	1.4d	0.47d	1.19b	100a	18.2a
One Way ANOVA (F-Statistics)								
F-Value		264.6***	466.8***	492.4***	357.0***	203.6***	0.0ns	599.1***
CV (%)		5.5	5.9	6.0	5.7	5.4	5.0	6.3

*: significant at *P*=.05; ***: significant at *P*=.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*=.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

Table 3. Summary of the results of the Cation Ratios and Total Exchangeable bases in the top soil samples (0 – 30 cm).

Mapping Unit	Texture	Ca/Mg	Mg/K	K/TEB	TEB
Muungano					
Mu-P1	CL	5.74a	3.86c	0.04b	19.54b
Mu-P2	SCL	3.57c	8.40b	0.02c	20.49b
Mu-P3	SCL	4.65b	0.79d	0.18a	18.59b
Mu-P4	C	1.81d	10.00a	0.03bc	37.23a
One Way ANOVA (F-Statistics)					
F Value		190.8***	457.9***	773.5***	149.4***
CV (%)		5.3	5.9	7.0	5.3
Mkombozi					
M-P1	SL	22.86a	3.50a	0.01b	18.13b
M-P2	SL-SCL	13.38b	1.51b	0.03a	27.00a
One Way ANOVA (F-Statistics)					
F Value		153.5***	326.4***	460.5***	89.3***
CV (%)		5.2	5.4	5.6	5.1
Endamajek					
E-P1	C	1.52c	3.67a	0.09c	41.14a
E-P2	C	1.20d	0.69d	0.39a	14.23c
E-P3	C	1.74b	2.23c	0.13b	36.96b
E-Hi2	SL-SCL	2.93a	2.98b	0.07d	7.16d
One Way ANOVA (F-Statistics)					
F-Value		178.1***	282.2***	585.3***	404.7***
CV (%)		5.3	5.5	6.3	5.8

***: 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; E: Endamajek; M: Mkombozi; Mu: Muungano (Mawemairo/Matufa); P: Profile;

3.2. Total Soil Organic Matter (OM)

Results of the present study revealed that, Soil Organic Carbon (% OC) of the top-soils in sites under study were generally very low (4.0 g kg^{-1}) to medium (19.1 g kg^{-1}) corresponding to OM of 6.9–32.9 g kg^{-1} (Table 2). Since OM content was calculated from soil organic carbon [23], these indicators had the same trend. Results also added that, organic carbon in most of the profiles generally decreased with increasing soil depth although not systematic. In Muungano (Mu-P4), the OC was 12.5 g kg^{-1} in the 50 cm of soil depth, increased to 13.4 g kg^{-1} in the next 50 cm soil depth while decreased to 1.1 g kg^{-1} in the next 50 cm of soil depth. This also applied to M-Pa1 in Mkombozi. It is generally accepted that a threshold for OM in most soils is 34 g kg^{-1} below which decline in soil quality is expected to occur [41]. Soil organic matter (OM) was below the proposed threshold values in all the sites under study, suggesting a decline in soil quality (Table 3). It is, therefore, apparent that there is a need to replenish the OM using resources such as crop residues and manure for maximum crop yields. Understanding the OM status before any development interventions are undertaken is of vital importance as it is extensively known to play a key role in the improvement of soil physical and chemical properties. These properties include structural stability, porosity, mineral elements availability (i.e. N, P and S); cation exchange capacity [35, 42, 43, 44, 45]; and soil moisture and nutrient holding capacity [14]. Soil organic matter has also been reported to have great impact on improving irrigation efficiency for sustainable land productivity; to enhance productivity and environmental quality; to reduce the severity and costs of natural phenomena, such as drought, flood, and disease; as well as to reduce atmospheric CO_2 levels that contribute to climate change [46, 47, 48, 49].

3.3. Total Nitrogen (TN)

According to results of the present study regarding total nitrogen (TN) status in the study areas was ranged 0.3 to 1.4 g kg^{-1} (Tables 2, 4). According to [33] guidelines, the proposed value for most crops in Tanzania is 2 g N kg^{-1} soil. The results show that all the surveyed sites had total N below the threshold value (< 2 g kg^{-1}) and was rated as low and or very low (Tables 2, 4). The observed low N in these areas may be attributed to, amongst others, low OM content which is greatly influenced by microbial activity in the soil [50] and high soil pH which could lead to N loss through ammonia volatilisation [51]. In our study, soil samples with relatively higher N levels were obtained from the relatively organic enriched soils. So, any activity envisaged to improve the soil pH, OM and microbial activities can, consequently, lead to an increase in the % N in the soil. Inadequate amounts of N in the soil are the primary factor that limits plant growth and development in many parts of the world [52; 53] suggesting short- and long-term interventions. Practices such as choice of cropping systems involving legumes with ability to symbiotically fix N_2 from the atmosphere, the use of artificial acidified nitrogen fertilisers, animal manure or composts are some of the means by which N input into the soil can be effected.

Table 4. *Soil fertility status for the selected schemes of Babati district.*

Soil fertility unit symbol	Texture	S	Soil fertility rating									Area	
		%	pH	TN	P	K	Ca	Mg	OM	CEC	ESP	Ha	%
Muungano													
MU-Pa11	CL	<1	N	L	L	M	VH	M	L	M	NS	170	20
MU-Pa12	SCL	<1	MA	VL	L	M	VH	H	L	M	NS	164	19
MU-Pa13	C	< 1	MA	L	H	VH	VH	M	L	M	NS	330	26
MU-Hi1	SCL	2-4	MA	L	L	M	H	VH	L	H	NS	303	35
Total Area (ha)												967	100
Gichameda													
M-Pa1	SL	< 1	SA	VL	H	L	VH	M	VL	L	MS	501	66
M-Pa2	SL-SCL	< 1	MA	L	H	H	VH	H	M	M	MS	216	29
Mu-Hi1												36	5
Total Area (ha)												753	100
Endamajek													
E-Pa11	C	< 1	MA	L	M	VH	VH	VH	M	H	NS	531	31.8
E-Pa21	C	< 1	MA	L	M	VH	H	H	M	M	NS	400	23.9
E-Pa22	C	< 1	MA	L	M	VH	H	VH	M	H	NS	297	17.8
E-Hi2	SL	< 5	MiA	L	M	H	H	H	M	L	SS	444	26.6
Total Area (ha)												1,672	100.0

Classification: According to NSS (1990) guidelines. MU = Muungano; M = Mkombozi; E = Endamajek; Pa = Plain; Pi = Piedmont; S (%) = Slope percent; TN = Total Nitrogen; P = Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; OM = Organic Matter; CEC = Cation Exchange Capacity; ESP = Exchangeable Sodium Percentage; SCL = Sand Clay Loam; CL = Clay Loam; C = Clay; N = Neutral; MA = Moderately alkaline; SA = Slightly alkaline; MiA = Mildly alkaline; M = Medium; VL = Very low; L = Low; H = High; VH = Very High

3.4. C/N Ratio

Results of C/N ratios in this study are shown in Tables 2 and 4 and ranged from 11 - 17 [33]. However, the most acceptable and favourable C/N ratio to most soils is 8 – 13. For adequate humification process, a C/N of 10 is considered as optimal. The result shows that the C/N ratio of most of the mapping units in the selected irrigation schemes was less than 15. These were rated as moderate to good quality organic matter (OM). Such conditions are favourable for most plants growth due to the fact that immobilization in the soil is less than mineralization. In the mapping unit Mu-P2, C/N ratio is 17, suggesting neutral conditions, that is, mineralization is equal to immobilization. The data also shows nitrogen (N) to be low to very low suggesting that in order to avoid leaching caused by rainfall or irrigation, ammoniocal form of N should be included in the fertiliser management program as it has better resistance to leaching. For example, a C/N ratio of more than 23 have been shown to favour slow degradation of residues by the associated micro-organisms, higher immobilisation effects and limited N in the soil leading to reduced crop yields [54, 55, 56]. The status of the C/N ratio in the surveyed areas suggests ideal conditions for plant growth, since in such situations mineralisation in the soil is greater than immobilisation.

3.5. Available Phosphorus (AP)

Most of soils in Muungano have ($P \leq 0.05$) low available phosphorus (AP). Results have shown that the available P was ranged from 1.7 – 23.72 mg kg^{-1} and rated as low and high. Of the total area surveyed, 65.9% was rated as low available P (Mu-P1; Mu-P2 and Mu-Hi1) and 33.1% as high available P (Mu-P3). The amount of available P in Mkombozi differed significantly ($P \leq 0.05$) between the two mapping units surveyed. As shown in Tables (2) and (4), available P in the two mapping units ranged from 22.38 to 33.34 mg kg^{-1} and was rated as high [33]. Referring the Endamajek, Av. P differed markedly across the mapping units. This was rated as medium and ranged from 5.1 to 9.86 mg kg^{-1} soil. An average P level of more than 7 mg kg^{-1} is considered optimal below which P – deficiency symptoms are likely to occur in most crops [33]. The observed low P in Muungano (Mu-P1, Mu-P2 and Mu-Hi2) and medium values of P in all the mapping units in Endamajek could partly be attributed to fixation into unavailable forms due to high soil pH especially in areas such as Muungano and Endamajek (Tables 2, 3). For example, in alkaline soils, calcium phosphates ($Ca_3 (PO_4)_2$) are less soluble, hence high P retention capacity and consequently low P availability [57]. Under such soil alkaline condition, phosphate fertilizer can be applied in bands with fertilizers which generate an ionized form of ammonia (NH_4^+). The generated NH_4^+ ion will allow slight acidification of the soil adjacent to the fertilizer band thereby creating favourable condition for P availability to plants. Similarly, compound nutrient fertilizer granules that contain the N, P, and sometimes elemental S can be applied into alkaline soils. Consequently, the soil adjacent to the granule will be acidified slightly and allow enhanced P uptake when the crop roots intercept the granules. Overall, future plans should include soluble P application (i.e. TSP, DAP or MAP) in these soils in order to moderate the P levels in the respective soils.

3.6. Exchangeable Bases (K, Mg, Ca)

3.6.1. Exchangeable Ca$^+$

The exchangeable Ca^{2+} in the topsoil of the Muungano (Mawemairo/Matufa) study area were significantly ($P \leq 0.05$) different from each other and ranged from 12.1 to 18.8

cmol (+) kg^{-1} soil in Mu-P3 and Mu-P4 respectively. The data showed that of the total area, 66% was rated as very high and 34% as high (Tables 2, 4). Exchangeable Ca in the top soils of Mkombozi scheme was not ($P \leq 0.05$) different from each other and ranged from 16.0 cmol (+) kg^{-1} (i.e. M-P1) to 17.4 cmol (+) kg^{-1} (i.e. M-P2). These were rated as very high. Results showed that exchangeable Ca in the top soils of Endamajek scheme were ($P \leq 0.05$) different and ranged from 4.1 cmol (+) kg^{-1} in E-Hi2 to 20.2 cmol (+) kg^{-1} in E-P1 rated as high to very high respectively. However, exchangeable Ca in E-P1 and E-P3 representing 50% of the surveyed area was greater ($P \leq 0.05$) compared with that observed in E-P2 and E-Hi2 (Tables 2, 4). [65] Proposed that in most crops, the recommended threshold level of Ca^{2+} is 5 cmol (+) kg^{-1}. Calcium deficiency occurs frequently in a range of crops when exchangeable Ca concentration is less than 1 cmol (+) kg^{-1} [66; 67]. It is generally acknowledged that field conditions that limit Ca^{2+} uptake produce lower crop yields than crops grown with adequate Ca^{2+} [68; 69; 70; 71]. The high to very high levels of Ca^{2+} in the study areas indicates lower bondage of Ca^{2+} to P at relatively lower soil reactions (Tables 2, 4).

3.6.2. Exchangeable Mg^{2+}

These results also showed that Mg^{2+} content in the topsoil of *Muungano (Mawemairo/Matufa)* study area ranged from 2.6 to 10.4 cmol (+) kg^{-1} soil and was rated as medium to very high. In this area, Mg content in the different mapping units was significantly ($P \leq 0.05$) different from each other. The data showed Mg was medium in 51.7%, high in 17.0% and very high in 31.3% of the total area surveyed (Table 2, 4). In *Mkombozi*, top soil Mg contents ranged from 0.7 to 1.3 cmol (+) kg^{-1} soil rated as medium to high. It was observed that Mg levels in M-P2 in 33% of the area were ($P \leq 0.05$) greater compared with M-P1 mapping unit which was 67% of the area surveyed (Table 2, 4). In *Endamajek*, Mg levels were ($P \leq 0.05$) different between mapping units. The data showed that Mg contents ranged from 1. 4 cmol (+) kg^{-1} in E-Hi2 to 13.3 cmol (+) kg^{-1} in E-P1. These were rated as high in 50% of the surveyed area (E-P2 and E-Hi2) and very high in 50% of the surveyed area (E-P1 and E-P3). The recommended value of Mg^{2+} in most crops is 2 cmol (+) kg^{-1} [60]. The observed levels of Mg^{2+} suggest that these areas have sufficient Mg^{2+} supplies for crop growth. Mg is required by a large number of enzymes involved in energy transfer, particularly those utilizing ATP; a constituent of the chlorophyll molecule; is required for the normal structural development of the chloroplast; as well as other organelles such as the mitochondrion [61, 62, 63, 64]. Thus, it is expected that Mg levels would be maintained or improved so as to avoid damaging effects on photosynthesis and respiration that would lead to poor crop yields.

3.6.3. Exchangeable K$^+$

In Muungano study area, significant differences ($P \leq 0.05$) were observed between the mapping units for potassium (K) levels in the soil which ranged 0.50 to 3.29 cmol (+) kg^{-1} soil (Table 3). These were rated as ($P \leq 0.05$) medium in 65.9%

(i.e. Mu-P1, Mu-P2, Mu-P4) and ($P \leq 0.05$) very high in 34.1% (i.e. Mu-P3) of the total area (i.e. 967 ha) assessed. Although K values in Mu-P1, Mu-P2 and Mu-P4 were rated as medium, Mu-P4 had ($P \leq 0.05$) higher value compared with others. In Gichameda, K levels were significantly ($P \leq 0.05$) different between the study areas (Table 2). Results showed that K ranged from 0.20 to 0.86 cmol (+) kg^{-1} soil, and was rated as low in 67% (M-P1) and high in 33% (M-P2) of the total area (i.e. 753 ha) surveyed. Comparatively, M-P2 has significantly ($P \leq 0.05$) greater K values compared with M-P1 (Tables 2). In Endamajek, K values ranged 0.47 to 5.48 cmol (+) kg^{-1} soil, and was rated as ($P \leq 0.05$) high in 27% to ($P \leq 0.05$) very high in 73% of the total area (i.e. 1,672 ha) assessed (Tables 2, 4). Comparatively, the data show that E-P3 has ($P \leq 0.05$) greater K levels compared with other mapping units. However, the ($P \leq 0.05$) lowest K value was observed at E-Hi2 mapping unit. It is generally accepted that response to K fertilisers is likely when a soil has an exchangeable K value of less than 0.2 cmol (+) kg^{-1} soil and unlikely when it is above 0.4 cmol (+) kg^{-1} soil [33; 58]. Based on the critical concentrations of exchangeable K values of 0.2 to 0.4 cmol (+) kg^{-1} soil, the data suggests that K is not a limiting mineral element to crop productivity in the study area [33, 59].

3.7. Cation Exchange Capacity

Results of the present study showed that there was significant ($P \leq 0.05$) difference in the cation exchange capacity (CEC) in Muungano soils which ranged 15.2 to 26.8 cmol kg^{-1} and rated as medium to high (Tables 2, 4) [33]. Several studies have shown that soils with CEC values between 6 to 12 cmol kg^{-1} are poor in exchangeable bases [33]. Of the total surveyed area in Muungano, 68.7% was rated as having medium CEC and 31.3% as having High CEC. CEC of top soils in *Mkombozi* ($P \leq 0.05$) differed between M-P1 and M-P2 fields surveyed. For example, CEC was highest in M-P2 (14.6 cmol kg^{-1}) and lowest in M-P1 (11.3 cmol kg^{-1}) (Tables 2, 4). These were rated as high and low respectively. Low CEC was observed in 67% and high in 33% of the total area assessed. Similarly, CEC in *Endamajek* ($P \leq 0.05$) differed between the areas surveyed with E-P1 and E-P3 being greater compared to E-P2 and E-P4. The data show that E-P1 (29.8 cmol kg^{-1}) and E-P3 (i.e. 27.8 cmol kg^{-1}) found in 50% of the total area assessed were highest compared with E-P2 (i.e. 18.5 cmol kg^{-1}) and 6.55 cmol kg^{-1} found in 24% and 27% of the total area assessed respectively (*see* Table 3, 5). According to [72], soils with low CEC are typically weathered with a low ability to support plant growth with adequate mineral element such as Ca. It is generally accepted that SOM is responsible for 25 - 90% of the total CEC of surface horizons of mineral soils [73; 74]. The low to medium CEC found in some areas in this study could be related to low SOM (Tables 2, 4). The low CEC values in soils have also been implicated with low yield in most agricultural soils [72]. Any intervention such as applying both manure and the required amount of fertiliser with the aim of improving the CEC of the soil is

recommended. By doing so, humus content of the soil will increase and, consequently, improve the CEC that may lead to better retention of mineral elements in the soil.

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

The exchangeable sodium (Na^+) in Muungano differed ($P \leq 0.05$) markedly between the mapping units assessed and ranged from 0.60 (Mu-P3) to 1.58 cmol (+) kg^{-1} soil (Mu-Hi1). These were rated as medium to high and occupies 51.7% and 48.3% of the total area assessed respectively. The corresponding ESP values ranged from 4.2 to 5.6% (Tables 2, 4) rated as non-sodic. In Mkombozi, Na^+ values ranged markedly from 1.23 to 1.73 cmol (+) kg^{-1} soil rated as high. These correspond to ESP values which ranged from 10.9 to 11.9% rated as moderately sodic. The Na values measured in Endamajek showed significant ($P \leq 0.05$) differences across different mapping units surveyed and varied from 0.45 to 1.58 cmol (+) kg^{-1} soil. Of the total area surveyed, 76% was rated as of high Na and 24% as of moderate Na values. The corresponding ESP values also differed markedly and ranged from 2.4 and 18.2% respectively. Of the total area assessed, 56% were non-sodic, 18% as slightly sodic and 27% as strongly sodic. The critical values of ESP above which most crops are affected are established at 15 [75]. The medium to high Na or slightly sodic to very strongly sodic status observed in this study may probably be related to high evaporation, poor management of irrigation water, lack of drainage systems and low Ca^{2+} due to high Na^+ concentrations in the exchange complex (Tables 2, 4). Higher Na^+ levels in the soil is associated with decline in net photosynthesis; energy losses for salt exclusion mechanisms; greater decrease in mineral elements uptake; poor NO_3^- assimilation required for plant growth; inhibition of vital enzymes and competition with K^+ [76, 77, 78, 79]. The excessive Na^+ in the soil is likely to cause reduced plant growth and development, thus, decreased crop yields [80, 81, 82, 83]. Our results suggest that such sodic soils may require appropriate amendments such as farm yard manure (FYM) and/or gypsum to reduce the concentration of Na^+ on the exchange complex, thereafter followed by leaching to replace the soluble Na^+ on the soil colloid, through irrigation or rain water [84; 2] and use of acidifying fertilisers such as sulphate of ammonia to lower the soil pH. Successful results on the use of locally available soil ameliorants, such as gypsum ($CaSO_4.2H_2O$) as a Ca^{2+} source and/or organic manure, has been reported in northern Tanzania [2].

3.9. Cation Ratios

The ratios of Ca: Mg, Mg: K and K: TEB in Muungano are shown in Table (3). Results indicated that Ca: Mg ratios in the mapping units surveyed were significantly ($P \leq 0.05$) different and they ranged 1.81 in Mu-P4 to 5.74 in Mu-P1. The data also added that Mu-P1 had ($P \leq 0.05$) greater Ca: Mg ratios compared with others, whereas Mu-P4 scored the lowest ratios. Similarly, Mg: K ratio ranged 0.79 in Mu-P3 to

10.0 Mu-P4 which was significantly ($P \leq 0.05$) greater compared with other mapping units. Likewise, the ($P \leq 0.05$) highest K: TEB ratio was recorded in Mu-P3 compared with Mu-P2. These values however, ranged from 0.02 to 0.18. The TEB was significantly ($P \leq 0.05$) different between the areas surveyed. Results showed that the lowest value (18.59) was recorded in Mu-P3 while, Mu-P4 scored the highest value (37.23). On the other hand, no significant differences were observed in TEB in mapping units under study (Mu-P1, Mu-P2 and Mu-P3).

The ratios of Ca: Mg, Mg: K, and K: TEB in Mkombozi were markedly different between the surveyed areas (see Table 3). For example, Ca: Mg ratio ranged 13.38 in M-P2 to 22.86 in M-P1 which was the greatest ($P \leq 0.05$) ratio as compared with M-P2. Results also showed that Mg: K ratio ranged 3.50 in M-P1 to 1.51 in M-P2 which was significantly lower ($P \leq 0.05$) compared with M-P1. Both of K: TEB ratio and TEB were recorded ($P \leq 0.05$) the lowest ratio (0.01 to 0.03 and 18.13 to 27.00) respectively in M-P1 as compared with M-P2.

Ca: Mg, Mg: K, K: TEB ratios and TEB in Endamajek mapping units was significantly ($P \leq 0.05$) different (see Table 4). The data showed that Ca: Mg ratios ranged 1.20 in E-P2 to 2.93 in E-Hi2 which was ($P \leq 0.05$) greater compared with other mapping units. It was also observed that Mg: K ranged between 0.69 in E-P2 to 3.67 in E-P1 it was significantly higher compared with other mapping units. K: TEB ratio ranged 0.07 in E-Hi2 to 0.39 in E-P2 which was markedly greater compared with other mapping units assessed. It was observed that TEB in the surveyed areas ranged 7.16 in E-Hi2 to 41.14 in E-P1which was (P ≤ 0.05) higher compared with the rest of the mapping units.

According to the established guidelines [33; 85], the recommended optimum ratio of Mg: K for most crops is 1- 4. Based on these results 51.7% of the surveyed area in Muungano, 100% in Mkombozi and 76% in Endamajek have values within the critical range suggesting favourable conditions for crop growth. The remaining areas have Mg: K ratios outside the critical range probably suggesting unfavourable conditions for crop growth. However, in areas where K was high, Mg was low and vice versa, suggests that these mineral elements are antagonistic. Research has indicated that the Ca: Mg ratio of 3 - 5 in the topsoil [33] is optimal for most crops. Based on this critical range, our data suggests less favourable conditions for most crops in all the surveyed areas except for 51.1% of the surveyed areas in Muungano (i.e. Mu-P2 and Mu-P3). The remaining surveyed areas in Mkombozi and Endamajek were either too high or too low. The availability of mineral elements for uptake by plants depends not only upon absolute levels but also on relative amounts of individual elements. It has been suggested that the optimal cation ratio for the growth of most crops in the tropical area is equal to 12.7: 3: 1 for Ca: Mg: K respectively [33]. Although the general trend for Ca: Mg: K doesn't indicate a good ratio in relation to the established standards, the individual nutrient ratios are more important i.e. Ca: Mg; Mg: K and K: TEB. Research has also indicated

that the K: TEB ratio of less than 2% is sub-optimal and may limit crop production [33]. Our results concluded that with the exception of 67% of the surveyed areas in Mkombozi (i.e. M-P1), the rest of the surveyed areas in Muungano and Endamajek have optimal values suggesting optimal conditions for plant growth. The less favourable conditions observed in Mkombozi (i.e. M-P1) suggest that plants would probably respond to the addition of Ca or Mg in such areas.

4. Conclusion

In conclusion, the results of the present study provide soil fertility status in the selected irrigation schemes. Data also suggest that soil 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, salinity and/or sodicity management in Tanzania, thus, contributing significantly in the efficient utilisation of land resources in the study areas.

Acknowledgements

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