Research article

Assessment of Soil Quality in Paddy Fields at Dakawa Irrigation Scheme, Morogoro, Tanzania

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Received 30 May 2023 Accepted 31 March 2025 (*Corresponding Author)

Abstract Soil quality, a measure of a soil's capacity to function, can be assessed using indicators based on physical, chemical, and biological properties. A soil quality assessment for soils used for rice production was conducted at the Dakawa Irrigation Scheme, located in Mvomero District, Morogoro, Tanzania. Eight disturbed soil samples, together with twenty-four undisturbed core soil samples, were obtained from two pitches (blocks 18 and 23) for laboratory analysis. The soil texture was identified as sandy clay loam for both pitches, and the pH levels in all layers of all pitches were rated as medium (5.7-7.0) to very high (7.0-8.6). The levels of organic carbon (OC) and organic matter (OM) were found to be very low, especially in the first layer for pitch one, where the average OM was 1.49% and OC was 0.83% and pitch two demonstrated OM of 1.34% and the OC was 1.08%. Average bulk density for all pitches was very high which cause soil compaction, all layers in each pitch has B.D> 2g/cm^3, for the case of permeability was very low ranges from 1.922 x 10^{-5} to 3.712 x 10^{-7} cm/s for pitch one and 1.2436 x 10^{-5} to1.89 x 10^{-7} cm/s. The cation capacity exchange (CEC) and exchangeable bases were rated as low to medium in all blocks. According to soil taxonomy and the world reference base for soil resources, the soil at the Dakawa Irrigation Scheme is classified as Vertic Calciusteps, fluvisols and Haplic Vertic combisols, respectively. It is recommended to increase the organic matter in the soil by applying organic matter. Additionally, the use of rice husk as a soil amendment should also be taken into consideration to control permeability and compaction.

Keywords soil quality, assessment, soil properties, paddy fields, Tanzania

INTRODUCTION

Rice is among the most important crops in the world, serving as a staple food to more than half of the world's population (Gnanamanickam et al., 2009). In Tanzania, rice is one of the most widely grown crops, and it is the second most important crop (Kolleh et al., 2017). Rice is both a cash and a food crop for the majority of people, and it is estimated that 60 percent of the population consumes rice each day (Achandi and Mujawamariya, 2016). The production of rice in Tanzania is an average of 1.8 tons/hectare (t/ha) (Mosha et al., 2022). The demand for this crop is growing rapidly daily as a food source in several countries of the world, following wheat (Gale et al., 2015). It was reported that there is a projected increase in rice demand from 680 million tons in 2015 to 771 million tons in 2030 (Bruinsma, 2017)

According to data from the Ministry of Agriculture (2022), the irrigation area in the country is 727,000 ha out of 29.4 million ha suitable for irrigation. Soil properties have also been reported as a contributing factor to rice growth. Usually, nutrient content and availability in soils determine the chemical and physical properties of that soil. Soils with high OM content are known to hold more nutrients necessary for paddy growth (Isdory et al., 2021). As soil OM content increases from 0.5

to 3.0%, the available water-holding capacity in the soil also increases. Therefore, low OM or losses of OM in the soils can significantly reduce paddy rice yields. Tanzania, like other developing countries in sub-Saharan Africa, is struggling to improve its rice yields. For instance, in the present study area, rice yields have ranged from 0.4 to 3.8 t/ha (average 1.87 t/ha). These yields were low compared to those in countries such as Egypt and the USA, where the average rice yields are close to 10 t/ha (Aagaard et al., 2019). Smallholder paddy rice growers in the present study sites have been complaining about uneven and low production, leading to low family income. Therefore, this study aimed to assess the impacts of soil quality on paddy rice productivity at the Dakawa Irrigation Scheme in Morogoro, Tanzania. The major factors contributing to the low yield include low soil fertility due to excessive nutrient mining coupled with low use of fertilizers, monocropping, poor agronomic practices, use of unimproved seeds, and poor access to output markets (Ngailo et al., 2016).

OBJECTIVE

The objective of the research is to assess the quality of soil at the Dakawa Irrigation Scheme in Morogoro, Tanzania.

METHODOLOGY

Description of the Study Area

The research was conducted at the Dakawa Irrigation Scheme in Mvomero District, Morogoro, Tanzania. The scheme has an area of 2000 ha and lies at Latitude 6°24'S and Longitude 37°33'E with a mean altitude of 361m a.m.s.l. It is located 45 km from Morogoro town, 7 km northeast of Wami-Dakawa village, and northwest of Wami River on an extensive flat plain. The Dakawa Irrigation Scheme has 29 Blocks (each block has 20 plots of 4.86 ha each).

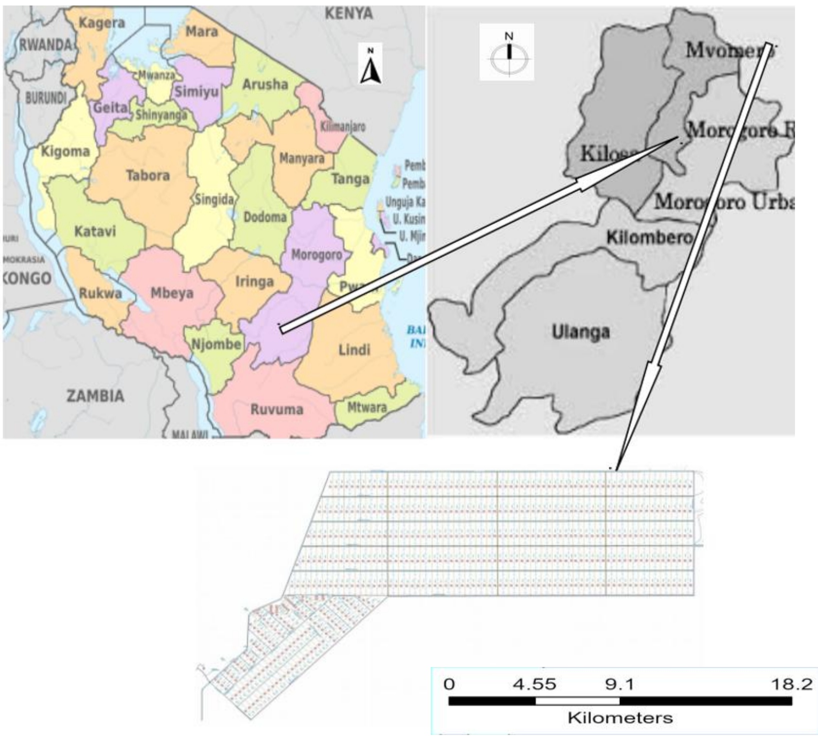

Fig. 1 Study area location

Soil Sampling

Soil samples were collected across the two blocks, block 18 (Pitch 1) and block 23 (Pitch 2) as shown in Fig. 3. In these blocks, farmers use a lot of fertilizer, and the soil appears to be compacted and the yield in this specific block is very low (0.5 ton/ha). Proper sampling equipment (soil auger and other related devices), representative sampling, timing of sample collection, multiple samples for variability, proper handling and transport, quality control in the laboratory analysis and data interpretation were the methods used to ensure the accuracy of soil sample collection and analysis. Both disturbed and undisturbed soil samples were collected, and the soil pitch where the soil samples were collected were excavated to 2 m deep with a surface area of 1 m x 1 m each pitch. At each pitch, four depths of 0.5 m were established, and at every depth 2 samples of undisturbed soil were taken, and one sample of disturbed soil was taken at each depth as well. After the sample, the soil was taken to the laboratory for the experiments and analysis for assessing soil quality.

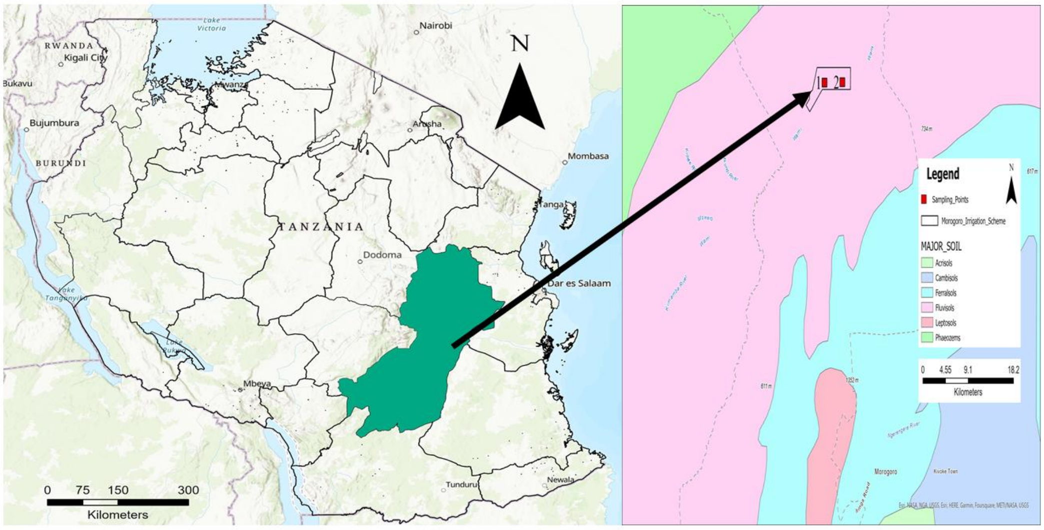

Fig. 2 Soil map with sampling points both having fluvisols soil

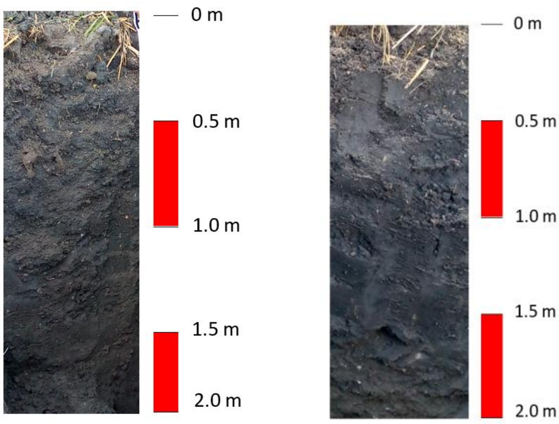

Fig. 3 Soil profile for pitches 1 and 2 at Dakawa Irrigation Scheme

Laboratory Experiments of Soil Quality

Both physical and chemical soil quality from Pitch one and Pitch two were measured and analyzed in the laboratory, For the case of permeability (k) was measured by using the falling head method and computed by using the following formula (1).

k =2.3al / (At) {log$_{10}$ *(h*$_1$*/h*$_2$*)}* (1)

Bulk density (BD) was measured by using the oven method and then computed by using the following formula (2).

BD = mass of oven dry soil / volume of soil (2)

Also, organic matter (OM) and organic carbon (OC) contents were measured in the laboratory by using the ignition loss method at temperature 800°C and then following formula (3) was used to compute the variables.

OM = (M1-M2) / M2 x 100% and *O.M = OC (%) x 1.72* (3)

For chemical properties assessments in the laboratory, at first the soil was treated with an excess of 1M neutral ammonium acetate to saturate the colloidal complex with ammonium, and the excess ammonium ions are removed by washing with alcohol. The ammonium in the soil is then determined by distillation in an alkaline medium, absorbed in boric acid, and titrated with sulfuric acid. Then, after filter paper, filtering funnel, filtration pump, weighing balance, flame photometer, atomic absorption spectrometer, volumetric flask, pH meter, and EC meter were all used to determine the chemical properties of soil in the laboratory.

RESULTS AND DISCUSSION

After laboratory experiments for both pitches, the results came as following tables below.

Table 1 Physical property assessed for Pitch 1

Layer	Depth (m)	Organic matter (%)	Orrganic carbon (%)	Moisture content (%)	Bulk density (g/cm^3)	Permeability (cm s^{-1})
1	0.0-0.5	1.49	0.83	1.51	1.5	1.922 x 10^{-5}
2	0.5-1.0	3.41	1.99	2.78	1.45	2.050 x 10^{-7}
3	1.0-1.5	3.84	2.23	3.58	1.49	3.71 x 10^{-7}
4	1.5-2.0	3.74	2.17	2.42	1.53	2.23 x 10^{-6}

Table 2 Physical properties assessed for Pitch 2

Layer	Depth (m)	Organic matter (%)	Orrganic carbon (%)	Moisture content (%)	Bulk density (g/cm^3)	Permeability (cm s^{-1})
1	0.0-0.5	1.34	1.08	1.8	1.63	1.24 x 10^{-5}
2	0.5-1.0	2.64	1.50	2.37	1.67	1.98 x 10^{-7}
3	1.0-1.5	3.31	1.92	2.79	1.52	1.89 x 10^{-7}
4	1.5-2.0	4.11	2.39	3.39	1.47	2.13 x 10^{-6}

Based on the physical soil assessments shown in Tables 1 and 2, the results of permeability for both pitches had low permeability less than 10^{-5} cm s^{-1}, which may cause the difficulty in nutrient from applied fertilizer, poor growth of plants, poor internal soil drainage and roots restriction which leads to poor productivity (Esringü et al., 2017).

Although the range of bulk density (BD) for paddy fields should range between range between 1.2 and 1.3 g/cm^3 (Liu et al., 2021), observed soil bulk density of the samples from both pitches was more than 1.4 g/cm^3, then the soil seems to have high compaction which may impose many stresses such as mechanical resistance, poor aeration and changes in hydrological system in soil, such as poor infiltration of water. According to the results, the bulk density obtained was higher at 0.15 to 0.47 g/cm^3 for both pitches than the recommended range of bulk density for paddy fields.

Organic matter (OM) contents ranged from 1.49 to 3.84% for Pitch 1, and 1.34 to 4.11% for Pitch 2. Although organic matter (OM) contents in paddy field are requested to be higher than 2%, OM in the first layer (topsoil) till 0.5 m were low as shown in Tables 1 and 2. Also, the lowest organic carbon (OC) contents were observed on the topsoil, as 0.8% for Pitch 1 and 1.08% for

Pitch 2 as shown in Tables 1 and 2. According to Landon (1991) and Bandyopadhyay et al. (2010), these values are rated as very low since they are < 2 %. Also, there was tendency that organic carbon (OC) contents increased with depth. The trend of OC being lower in the topsoil than other layers, it may be caused during the levelling process with the removal of topsoil which has higher organic carbon (OC) contents. For rehabilitating topsoil, some measures should be done for improving organic matter (OM) and organic carbon (OC) contents for higher rice productivity.

Table 3 Chemical properties assessed for Pitch 1

Layer	Depth (m)	pH in H_2O	EC (mS/cm)	Cl (mg/kg)	CO_3 (mg/kg)	HCO_3 (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	K (mg/kg)
1	0.0-0.5	7.54	266	77.97	335	976	110	1711.2	29.9	478
2	0.5-1.0	8.00	278	63.79	330	795	116	1905.6	271.4	429
3	1.0-1.5	8.56	446	99.23	210	976	120	1813.2	460.0	468
4	1.5-2.0	8.48	576	120.5	210	793	136	1918.8	558.9	468

Table 4 Chemical properties assessed for Pitch 2

Layer	Depth (m)	pH in H_2O	EC (mS/cm)	Cl (mg/kg)	CO_3 (mg/kg)	HCO_3 (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	K (mg/kg)
1	0.0-0.5	7.92	291	78.77	340	998	118	1790.4	110.4	472
2	0.5-1.0	8.10	288	72.54	320	893	122	2078.7	347.3	586
3	1.0-1.5	8.60	489	100.00	230	992	130	1921.2	457.7	507
4	1.5-2.0	8.51	591	128.12	225	801	140	1920.0	577.3	585

Chemical Properties

Some chemical properties of both of soil profile are summarized in Tables 3 and 4. The highest soil pH in Pitch 1 was 8.56, and 8.51 in Pitch 2. These highest pH values were observed at the depths from 1.0 to 1.5 m. For both pitches, there was a tendency for soil pH to increase with depth from the topsoil. Landon (1991) rated these pH values as very high (7.0-8.5). High soil pH of this soil could be attributed to relatively high concentrations of Na, Ca, and Mg, which were also increasing with soil depth. The Na might be originating from surface evaporation of water in the Wami River, containing a substantial amount of Na due to alluvial deposition (Kisetu et al., 2013). Some measures should be taken to reduce soil pH, as those ranges indicate the soils are alkalinity (Tokpah et al., 2017).

	k	OM	OC	BD	pH	EC	Cl	CO_3	HCO_3	Ca	Mg	Na	K
k	1	-0.485	-0.516	-0.467	-0.908	-0.485	0.592	0.578	0.95	-0.744	-0.998	-0.935	0.581
OM		1	1	0.621	0.542	0.046	-0.976	-0.661	-0.948	0.349	0.854	0.83	-0.982
OC		**	1	0.131	0.492	0.246	-0.961	-0.522	-0.895	0.456	0.891	0.775	-0.894
BD				1	0.764	0.943	0.138	-0.361	-0.25	0.938	0.522	0.449	0.051
pH		**	**	**	1	0.807	-0.529	-0.566	-0.742	0.932	0.929	0.796	-0.537
EC				**	**	1	0.033	-0.151	-0.211	0.9	0.532	0.349	0.065
Cl	*						1	0.486	0.857	-0.209	-0.762	-0.693	0.937
CO_3	*							1	0.848	-0.566	-0.745	-0.929	0.748
HCO_3	**						**	**	1	-0.562	-0.937	-0.965	0.954
Ca				**	**	**				1	0.785	0.587	-0.292
Mg		**	**		**					**	1	0.938	-0.81
Na		**	**		**					*	**	1	-0.852
K	*						**	**	**				1

1.00	-0.10
0.90	-0.20
0.80	-0.30
0.70	-0 .40
0.60	-0.50
0.50	-0.60
0.40	-0.70
0.30	-0.80
0.20	-0.90
0.10	-1.00
0.00	

Notes: ***k****: Permeability;* ***OM****: Organic matter;* ***OC****: Organic carbon;* ***BD****: Bulk density;* ***pH****: Soil pH;* ***EC****: Electric conductivity;* ***Cl****: Chloride;* ***CO3****: Carbonate;* ***HCO3****: Hydro carbonate;* ***Ca****: Calcium,* ***Mg****: Magnesium;* ***Na****: Sodium;* ***K****: Potassium, **p < 0.01, * p <0.05*

Fig. 4 Correlation matrix among soil properties analyzed at Dakawa Irrigation Scheme

Electrical Conductivity (EC) values ranged between 266 and 576 mS/cm at Pitch 1, and the average EC value was 391.5 mS/cm. Also, EC values ranged between 291 and 591 mS/cm at Pitch 2 with the average of 414.8 mS/cm for all soil layers of Pitch 2. As shown in Tables 1 and 2, other chemical properties, such as Cl, CO_3, HCO_3, Ca, Mg, Na, and K are assessed in both pitches are as standard and they matched up with the FAO guidelines of soil for paddy production (FAO, 2021).

Correlation Among Soil Properties

The correlation matrix among soil physical and chemical properties analyzed at Dakawa Irrigation Scheme was summarized in Fig. There were significant correlations between organic matter (organic carbon) contents and soil pH, magnesium and sodium concentrations, respectively. Also, soil pH values were related with electric conductivity, calcium, magnesium and sodium concentrations, respectively.

CONCLUSION

Since this assessment has identified problems of low permeability, high bulk density, which led to soil compaction, very low OM and OC, and also the emergence of alkalinity of the soil which all of which at the end lead to poor productivity in particular areas. In this case, it is recommended to increase the OM and OC and control soil pH by using organic matter of cow dung compost, this is due to the fact that it's available in the area and it's very easy to make application of it. Additionally, the use of rice husk as a soil amendment should also be taken into consideration to control permeability and compaction. It is recommended to use rice husk because of its efficiency and it's available in the area of the Dakawa Irrigation Scheme.

ACKNOWLEDGEMENTS

Special thanks are given to the government of the United Republic of Tanzania through the Ministry of Agriculture for many supports to advance this research. Also, many thanks to JICA as well as research fellows at the Laboratory of Land and Water Use Engineering, Tokyo University of Agriculture for meaningful suggestions and mental support during the research.

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