**Impact of Agricultural Land Management Practices on Soil Quality in Tatkon Township, Myanmar**

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ABSTRACT

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| In Myanmar, agricultural land has been utilized intensively for many purposes regardless of proper management, which is challenging to sustainable agricultural production. Farmer are typically grown rice, sunflower and maize based cropping pattern in Tatkon Township. This research aimed to evaluate agricultural land management practices on some soil properties with the Soil Quality Indicators (SQI) in the study area. For the study area, there were six land management practices in a year, namely, rice mono-cropping (L1), sunflower-based two crops (L2), maize-based two crops (L3), sunflower-based three crops (L4), maize-based three crops (L5), and sunflower-chickpea (L6). The soil samples were collected with grid point method from February to April 2023. Twenty-four soil samples were collected from six land management practices for soil analysis. Then, soil bulk density, soil organic matter (SOM), soil pH and electrical conductivity (EC), Total N, available P, cation exchangeable capacity (CEC), and exchangeable K, available Ca, Mg, and Na were analysis at YAU. Data were analyzed by Statistix (version 8). The results show that different land management practices were statistical differences in some soil properties at *P* = .01 and *P* = .05, respectively. L1 obtained the highest bulk density, while the lowest values were in CEC, SOM, available P, exchangeable K, available Ca, and available Mg content. L2 possessed the highest CEC value, available K, and available Ca content, whereas the lowest in EC and total N percent. L3 obtained the highest EC value, total N percent, and lowest soil pH. L4 possessed the highest available Na content. L5 obtained the highest soil pH and available P content. L6 possessed the highest SOM percent and available Mg, while the lowest bulk density, EC, and available Na content.  According to the defined soil quality indicators, sustainable land management practices for agricultural production in the study area showed in the order of L2 > L6 > L5 > L3 > L4 > L1. Therefore, this study highlighted sunflower-based two crops (L2) had the optimum land management practices for sustainable agricultural production and maintaining soil fertility. Considering the most effective and affordable soil analysis, the available Ca parameter could be chosen because of CEC, which is a soil chemical indicator showing how soil fertility status, is the most strongly correlated with available Ca among other correlated soil properties. This study suggested that rice mono-cropping have lower soil fertility than other land management practices. This study can help for local farmer in implementing soil fertility management and effective crop management program for long term soil quality. |

*Keywords: Land management practices, soil properties, soil quality indicators*

1. INTRODUCTION

Agriculture is a vast system and practice of different farming processes benefiting humans and animals. It plays a vital role in Myanmar's economy, providing more than 60.69% of employment for the people of Myanmar [15]. Agricultural land management practices were crucial in determining soil health and productivity [22]. The global goal emphasized to promote good soil management that can help migrate climate change. Farmer and land managers primarily apply management practices to improve soil condition [33]. One of the concepts of regenerative agriculture is soil-based, through enhancement and sustainable management of soil health by managing SOM content, nutrient recycling and increasing soil resilience to climate change [34]. According to [17], appropriate land management practices are required to decrease critical land and improve land productivity while reducing soil degradation and maintaining better soil quality. In the world of agriculture and horticulture, soil quality has become more important as a tool for evaluating different production systems [3,16]. As soil quality is a complex concept that cannot be measured directly in the field or laboratory, it can be identified from the characteristics of soil and a range of soil parameters [10,24].

Most soil scientists use soil quality indicators (SQI) to evaluate how well soil functions measure soil properties and identify responsive soil management practices for assessing the sustainability of land resources [13]. Soil quality indicators may be qualitative or quantitative. Establishing a minimum data set from the measured soil properties and the resulting qualitative or quantitative scores has been used as a quantitative tool to establish a linkage between soil health encompassing physical, chemical, and biological properties of soil and a management goal [1,2,18,28]. SQI can often be used to measure soil function, as it considers multiple soil properties to provide a comprehensive evaluation of soil health and productivity [19]. A soil quality indicator shows an optimum level which means the soil has a higher performance than other levels. This approach can help farmers to identify problem areas and carry out focused treatments to improve soil health and increase crop yield [7].

In Tatkon township, most farmers used to practice intensive cultivation and the dominant cropping patterns were rice-based, maize-based, and sunflower-based crops. Therefore, it necessitates knowing the extent of soil quality in terms of soil physicochemical properties under different agricultural land management practices. The effects of cropping patterns and land management practices in the study area are not fully understood, and there is insufficient information about soil properties. The objective of this study is to evaluate agricultural land management practices on some soil properties by using SQI in the study area.

2. material and methods

**2.1 Site Description**

The study was conducted at Kin Mun Tan village tract in Tatkon Township. It is located between 20° 09’ 81” N latitudes and 96° 19’ 41” E longitudes, 59 km north of Nay Pyi Taw. It is found within the subtropical climatic zone with a mean annual rainfall of 81.28 mm and an average annual temperature of 31°C. Supplementary irrigations is usually practiced, and the areas under an abundance of irrigation perform rice-rice cropping and the areas with not enough water carry out dry land farming. The dominant crops produced in the dry land are sunflower and maize. On the other hand, sesame, tomato, onion, cabbage, chili, and legumes are rotated with the maize and sunflower.

**2.2 Soil Sampling**

The soil samples were collected at 0 - 20 cm depths following the harvest of the winter season crops using an auger and a core sampler (which gathers undisturbed soil samples for bulk density measurements) from February to April 2023. The grid point sampling method is used with a 95 m × 95 m grid point for soil property analysis. Twenty-four soil samples were collected from various land management practices by purposive sampling techniques, with four replications. Ten soil cores from one grid plot were collected as undisturbed soil, and ten soil samples from disturbed soil were combined into a single sample.

**Table 1. Different agricultural land management practices in the study area**

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| **Land management practices** | **Cultivation practices** | **Replications** |
| L1 | Rice -Rice | rice - rice |
| L2 | Sunflower-based 2 crops | sunflower - chili |
| sunflower - sunflower |
| sunflower - cotton |
| sunflower - cabbage |
| L3 | Maize-based 2 crops | maize - spinach |
| maize - cabbage |
| maize - chili |
| maize - parsley |
| L4 | Sunflower-based 3 crops | sunflower - chickpea - chili |
| sunflower - chickpea - chili |
| sunflower - chili - lablab bean |
| sunflower - chili - lablab bean |
| L5 | Maize-based 3 crops | maize - chickpea - chili |
| maize - chickpea - chili |
| maize - chickpea - onion |
| maize - chickpea - onion |
| L6 | Sunflower-chickpea | sunflower - chickpea |
| sunflower - chickpea |
| sunflower - chickpea |
| sunflower - chickpea |

**2.3 Preparation, Laboratory Analysis, And Procedures**

After the composite soil samples were allowed to air-dry, samples were passed through a 2 mm sieve. Then, partitioning, packaging, and labeling were done. Soil analysis was conducted at the Soil and Water Science Laboratory, ELB-1, Yezin Agricultural University. The soil BD (undisturbed soil) was analyzed using the core sampler method by drying the soil at 105 °C (Baruah and Barthakur, 1997. Soil organic matter (SOM) was determined by using wet digestion method (Rayment and Lyons, 2011) and calculated by multiplying the percentage of soil organic carbon in the soil by 1.724 (Sakar and Haldar, 2005). Soil pH and electrical conductivity (EC) were determined by using 1:5 (soil: water) (Hesse, 1971) and measured with pH meter (AS ONE/AS800) and EC meter (CD 4307 SD). Cation exchangeable capacity (CEC) and exchangeable K, available Ca, Mg, and Na in soil were determined by 1N NH4Cl extraction method (Rayment & Lyons, 2011) and measured with HITACHI/ZA3000. Total nitrogen (N) was determined by modified Kjeldahl digestion method (Ohyma et al., 1991). Available phosphorus (P) was measured with a Spectrophotometer (SHIMADZU/A109349) after extraction with (Olsen, 1962) method. The results were evaluated with the defined soil quality indicators (Table 2)

**2.4 Statistical Analysis**

The Statistical Package for Social Scientists (SPSS) (Version 25) and Statistix (version 8) were used to analyze the data. The minimum, maximum, mean, standard deviation, standard error, and coefficient of variation were all described using descriptive statistics.

**Table 2. Lists of soil quality indices (SQI) used with references**

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| --- | --- | --- |
| **Soil properties** | **SQI** | **References** |
| Bulk density (g cm−3) | Optimum level for  irrigation and root penetration  (1.3-1.5 ) | FAO (2023) |
| pH | < 5.1 – strongly acidic  5.2 - 6.0 – moderately acidic  6.1 - 6.5 – slightly acidic  6.6 - 7.3 – neutral  7.4 - 8.4 -moderately alkaline  > 8.5 – strongly alkaline  Acceptable range (6.0 -7.5) | Horneck et al. (2011)  FAO (2021) |
| EC (dS m−1) | < 0.5 – low  0.5 - 2.0 – medium  > 2.0 – high | Moore (2001) |
| SOM (%) | < 2.0 – very low  2.0 - 3.0 – low  3.0 -7.0 – optimum  7.0 - 8.0 – high  > 8.0 – very high | Ethiosis (2014) |
| CEC (cmol(+) kg−1 soil) | <6 – very low  6 -12 – low  12 - 25 – medium  25 - 40 – high  >40 – very high | Hazelton and Murphy (2007) |
| Total N (%) | < 0.1% – very low  0.1 - 0.15% – low  0.15 - 0.3% – optimum  0.3 - 0.5% – high  > 0.5% – very high | Ethiosis (2014) |
| Available P (mg kg−1) | <10 – low  10 - 20 – medium  20 - 40 – high  >40 – excessive | Motomizu et al. (1983) |
| Exchangeable K (mg kg−1) | <150 – low  150 - 250 – medium  250 - 800 – high  >800 – excessive | Horneck et al. (2011) |
| Available Ca (mg kg−1) | <1000 – low  1000 - 2000 – medium  >2000 – high | Horneck et al. (2011) |
| Available Mg (mg kg−1) | <60 – low  60 - 300 – medium  >300 – high | Horneck et al. (2011) |
| Available Na (mg kg−1) | <640 – suitable  640 - 1600 – marginal  >1600 – unsuitable | Horneck et al. (2011) |

**3. RESULTS AND DISCUSSION**

**3.1 Effect of Different Agricultural Land Management Practices on Some Soil Physicochemical Properties**

**3.1.1 Soil bulk density**

In Figure 1(a), there were significant differences in soil bulk density between soil samples from different land management practices at *P* = .05. Of these practices, L6 (1.26 g cm−3) had the lowest bulk density (BD), followed by L2 (1.28 g cm−3). On the other hand, L1 had the highest bulk density (1.48 g cm−3). In general, rice-rice (mono-cropping) showed higher BD than the rotated cropping practices. Table 2 describes the ideal critical levels (1.3 - 1.5 g cm−3) for soil conditions that support plant root growth and water-holding capacity. Higher bulk density leads to more soil compaction, which reduces air volume and causes re-arrangement of soil particles and closer packing of the soil weight, creating unfavorable plant growth and development [4,5,8,9,12,]. However, the mean bulk density in the study area is 1.33 g cm−3, and it is not restricted to cultivation.

**3.1.2 Soil organic matter**

The soil organic matter was not significantly different among the different land management practices at *P =* .05 (Figure 1(b)). The highest percentage of soil organic matter (SOM) was observed in L6, followed by L3, L4, L2, and L5, whereas L1 had the lowest percentage of SOM. Table 2 describes the optimum SOM range should be 3% < SOM < 7%. This study had a low range of SOM due to different land management practices. It indicates that an improperly intercropped and crop-rotated field, as well as continuous cropping, may cause an organic carbon (OC) decline. Several authors discussed that intensive agricultural land management techniques and tillage reduced soil organic carbon [23,26].

**3.1.3 Electrical conductivity (EC)**

Figure 2(c) showed that there were no significant differences in EC due to different land management practices in the study area (*P =* .05). Numerically, L3 had the maximum value of soil EC (0.16 dS m−1), followed by fields L4 and L5 (0.12 dS m−1), L1 and L2 (0.10 dS m−1) while field L6 had the minimum (0.08 dS m−1). According to SQI, all fields were in the low range (EC <2 dS m−1) and all soil properties were under non-saline conditions. A possible explanation for the low EC was not related to irrigation water quality and salt problems. Even the study area was operated under the irrigated farm with the furrow irrigation system, and the monsoon’s heavy rainfall facilitated the timely leaching of salts from the root zone. A similar discussion has already been proposed by [25].

**3.1.4 Soil pH**

The soils in the study area showed some significant differences in soil pH under different agricultural land management practices (in Figure 2(d)). The pH of the soils changed significantly from 7.75 in L5 to 6.67 in L3. Based on the classification by SQI, the mean value of soil pH (7.17) in all land management practices indicated the study soil as neutral. According to Table 2, the pH values of most soils were within the critical range (6–7.5). Three crops per year practices (both L4 and L5) showed above the critical range. However, it may not be a problem for crop cultivation and land management practices in the study area. The highest pH in L4 and L5 could be associated with low leaching of basic cations from soil exchange complexes, which was also reported in [21,27].

**3.1.5 Soil total nitrogen**

According to different land management practices, there was no significant difference in total N content (Figure 3€). All soils showed under the low range of total N (<0.15%). Numerically, L3 had the highest soil total nitrogen percentage (0.14%), followed by L6 (0.13%), L4 (0.10%), and L5 (0.10%), whereas L2 showed the lowest total N (0.06%), followed by L1 (0.08%). The low range of total N in the study area was concerned with very low OM content (Table 3). In addition, it could be assumed that the applied nitrogen fertilizers were completely consumed by plants. Some N could be lost due to runoff and evapotranspiration process, [30].

**3.1.6 Soil available phosphorus**

In Figure 3(f), there were significant differences in the available P contents among different land management practices at *P =* .01. L5 had the highest available P content (10.75 mg kg−1), followed by L4 (9.55 mg kg−1), L2 (7.87 mg kg−1), L3 (6.95 mg kg−1), L6 (5.94 mg kg−1), and L1 (1.58 mg kg−1), respectively. Most soil properties were in the low range of available P (<10 mg kg−1). In this study, soils with low available P were related to soil pH and BD (Table 3). [31] confirmed that different land management practices including crop management intensity and duration had a significant impact on P in soils. Moreover, these practices were one of the key factors for the behaviors of available P in soils.

**3.1.7 Soil cation exchange capacity**

In Figure 4(g), there was a significant difference in soil cation exchange capacity due to different land management practices at *P =* .05. L2 (18.29 cmol(+) kg−1) had the highest cation exchange capacity (CEC), followed by L3 and L6 (15.9 cmol(+) kg−1). On the other hand, L1 had the lowest CEC (12.85 cmol(+) kg−1). In the study area, all soil properties showed in the medium CEC range (6.5-20 cmol(+) kg−1). Noticeably, rice-rice (mono-cropping) and three cropping practices associated with low cation exchange capacity and sunflower rotated with vegetable cropping practices maintained higher CEC levels. Several authors pointed out that crop rotation is associated with long-term soil land management practices, and it positively affected soil OC and CEC. In this study, CEC values were related to SOM, exchangeable K, available Ca, and available Mg (Table 3).

***3.1.8 Soil exchangeable potassium***

Figure 4(h) showed that L2 had the highest exchangeable K (250.25 mg kg−1), followed by L5 (201.63 mg kg−1), L4 (197.99 mg kg−1), whereas L1 had the lowest exchangeable K content (57.14 mg kg−1). Exchangeable K due to different land management practices did not differ statistically in this study. Except for L1, all soil properties were in the medium range of exchangeable K (150-250 mg kg−1). This study pointed out that rice-rice (mono-cropping) practices lower exchangeable K content in the soil. Most studies discussed that mono-cropping rice production practice often leached the exchangeable K from the soil due to continuous irrigation and insufficient potassium fertilizer inputs [14,20].

**3.1.9 Soil available calcium**

The different agricultural land management practices showed some statistical differences in soil available Ca at *P* = .05 (in Figure 5(i)). L2 had the highest available Ca content (2469.92 mg kg−1), followed by L3 (2082.82 mg kg−1), L6 (2027.57 mg kg−1), L4 (1889.95 mg kg−1), L6 (1700.55 mg kg−1), and L1 (1670.44 mg kg−1), respectively. According to SQI, L2, L3, and L6 showed in the high range of available Ca (>2000 mg kg−1) and the rest remained in the medium range (1000-2000 mg kg−1). The study area showed that there was no problem in available Ca which was highly correlated to CEC (Table 3). Intensive land management practices such as L1, L4, and L5 had numerically low in available Ca. Some studies discussed that flooding of rice mono-cropping increased the solubility of calcium and other base cations, making them more susceptible to leaching [29,32]. More in detail, [11] reported that this leaching resulted in a decrease in soil calcium levels, further exacerbating nutrient deficiencies in intensive cropping systems.

**3.1.10 Soil available magnesium**

Numerically, L6 had the highest available Mg levels (617.29 mg kg−1) in figure 5(j), followed by L2 (606.89 mg kg−1), L5 (576.82 mg kg−1), L3 (562.09 mg kg−1), L4 (551.47 mg kg−1), and L1 (497.69 mg kg−1). However, there were no statistical differences in available Mg contents among different land management practices. According to SQI, all soil properties showed a high range of available Mg content (>300 mg kg−1). The possible reason for the high available Mg was that the soil of the study area was derived from magnesium-rich parent material [6].

**3.1.11 Soil available sodium**

L4 yielded the highest available Na (76.90 mg kg−1), followed by L3 (75.37 mg kg−1), L5 (60.03 mg kg−1), L2 (55.22 mg kg−1), L1 (46.57 mg kg−1), and L6 (30.64 mg kg−1), respectively (in Figure 6(k)). However, available Na under different land management practices did not differ significantly in this study. According to SQI, all soil properties showed a low range of available Na (<640 mg kg−1). This range represented a suitable level for the cultivation of various crops and no problematic in irrigation water quality there.

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| L1 - Rice –Rice L2 - Sunflower-based 2 crops L3 - Maize-based 2 crops  L4 - Sunflower-based 3 crops L5 - Maize-based 3 crops L6 - Sunflower-chickpea  *Different letters on the bars showed statistically different at P = .05* | |
| **Figure 1. Effect of different agricultural land management practices on (a) soil bulk density and (b) soil organic matter** | |

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| --- | --- |
|  |  |
| L1 - Rice –Rice L2 - Sunflower-based 2 crops L3 - Maize-based 2 crops  L4 - Sunflower-based 3 crops L5 - Maize-based 3 crops L6 - Sunflower-chickpea  *Different letters on the bars showed statistically different at P = .05* | |
| **Figure 2. Effect of different agricultural land management practices on (c) soil electrical conductivity and (d) soil pH** | |

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| --- | --- |
|  |  |
| L1 - Rice –Rice L2 - Sunflower-based 2 crops L3 - Maize-based 2 crops  L4 - Sunflower-based 3 crops L5 - Maize-based 3 crops L6 - Sunflower-chickpea  *Different letters on the bars showed statistically different at P = .05* | |
| **Figure 3. Effect of different agricultural land management practices on (e) soil total nitrogen and (f) soil available phosphorus** | |

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| --- | --- |
|  |  |
| L1 - Rice –Rice L2 - Sunflower-based 2 crops L3 - Maize-based 2 crops  L4 - Sunflower-based 3 crops L5 - Maize-based 3 crops L6 - Sunflower-chickpea  *Different letters on the bars showed statistically different at P = .05* | |
| **Figure 4. Effect of different agricultural land management practices on (g) soil cation exchange capacity and (h) soil exchangeable potassium** | |

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| --- | --- |
|  |  |
| L1 - Rice –Rice L2 - Sunflower-based 2 crops L3 - Maize-based 2 crops  L4 - Sunflower-based 3 crops L5 - Maize-based 3 crops L6 - Sunflower-chickpea  *Different letters on the bars showed statistically different at P = .05* | |
| **Figure 5. Effect of different agricultural land management practices on (i) soil available calcium and (j) soil available magnesium** | |

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| L1 - Rice –Rice L2 - Sunflower-based 2 crops L3 - Maize-based 2 crops  L4 - Sunflower-based 3 crops L5 - Maize-based 3 crops L6 - Sunflower-chickpea |
| **Figure 6. Effect of different agricultural land management practices on (k) soil available sodium** |

**3.2. Correlation Between Soil Physicochemical Properties**

Table 3 illustrates the results of Pearson's correlation analysis between the measured soil physicochemical properties. In the study area, the bulk density of soil showed a negative correlation with both CEC (*r*=-0.434 at *P = .05*) and available P (*r*=-0.506 at *P = .05*). These meant that the soils with higher BD showed lower CEC and lower available P. Furthermore, the relationship between soil pH and available P showed a positive correlation (*r*=0.440 at *P = .05*). In literature, available P was dependent on soil pH range. There was a positive correlation between the soil EC and available Na (*r*= 0.666 at *P = .01*). The soil CEC exhibited a positive correlation with SOM (*r*=0.538 at *P = .01*), exchangeable K (*r*=0.709 at *P = .01*), available Ca (*r*=0.958 at *P = .01*), available Mg (*r*=0.571 at *P = .01*), and available P (*r*=0.478 at *P = .05*). SOM showed a positive correlation with total N (*r*=0.513 at *P = .05*), with exchangeable K (*r*=0.475 at *P = .05*), and with available Ca (*r*=0.477 at *P = .05*). The available P showed a positive correlation with both exchangeable K (*r*=0.716 at *P = .01*) and available Mg (*r*=0.576 at *P = .01*). The exchangeable K positively correlated with both available Mg and Ca (*r*=0.571 and 0.557 at *P = .01*). Among the correlated soil physicochemical properties, CEC showed the best parameter which was highly related to the other four soil properties and strongly correlated with available Ca (*r*=0.958). In Myanmar, the determination of soil CEC test is more expensive than available Ca measurement. The cost of the available Ca test was twice and half lower than that of CEC.

**Table 3. Correlation between soil physicochemical properties**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **BD** | **pH** | **EC** | **CEC** | **SOM** | **N** | **P** | **K** | **Ca** | **Mg** | **Na** |
| **BD** | **1** |  |  |  |  |  |  |  |  |  |  |
| **pH** | **.023** | **1** |  |  |  |  |  |  |  |  |  |
| **EC** | **-.293** | **-.287** | **1** |  |  |  |  |  |  |  |  |
| **CEC** | **-.434\*** | **-.146** | **-.008** | **1** |  |  |  |  |  |  |  |
| **SOM** | **-.371** | **-.222** | **.182** | **.538\*\*** | **1** |  |  |  |  |  |  |
| **N** | **-.221** | **-.116** | **.014** | **.149** | **.513\*** | **1** |  |  |  |  |  |
| **P** | **-.506\*** | **.440\*** | **.171** | **.478\*** | **.289** | **.176** | **1** |  |  |  |  |
| **K** | **-.403** | **.112** | **.138** | **.709\*\*** | **.475\*** | **.034** | **.716\*\*** | **1** |  |  |  |
| **Ca** | **-.350** | **-.285** | **-.023** | **.958\*\*** | **.477\*** | **.103** | **.303** | **.571\*\*** | **1** |  |  |
| **Mg** | **-.384** | **.282** | **-.150** | **.571\*\*** | **.351** | **.218** | **.576\*\*** | **.557\*\*** | **.328** | **1** |  |
| **Na** | **-.215** | **.001** | **.666\*\*** | **.117** | **.256** | **.118** | **.234** | **.044** | **.134** | **-.186** | **1** |

BD- bulk density, EC- electrical conductivity (dS m−1), CEC- cation exchange capacity (cmol(+) kg−1), SOM-soil organic matter (%), N- total nitrogen (%), P- available phosphorus (mg kg−1), K- exchangeable potassium (mg kg−1), Ca- available calcium (mg kg−1), Mg- available magnesium (mg kg−1), Na- available sodium (mg kg−1).

\*means significantly different at *P* = .05, \*\* means highly significantly different at *P =* .01

**4. CONCLUSION**

Among the land management practices, L1 had the highest bulk density but the lowest values for CEC, SOM, available P, exchangeable K, available Ca, and available Mg. L2 exhibited the highest CEC, available K, and available Ca, while having the lowest EC and total N content. L3 recorded the highest EC and total N percentage but had the lowest soil pH. L4 had the highest available Na content. L5 showed the highest soil pH and available P. L6 had the highest SOM and available Mg content while exhibiting the lowest bulk density, EC, and available Na.

Based on Soil Quality Indices (SQIs) and the soil fertility index (CEC), the effectiveness of different agricultural land management practices follows the order: L2 > L6 > L5 > L3 > L4 > L1. Since CEC is strongly associated with various soil properties and closely correlates with available calcium, it serves as a cost-effective soil quality indicator for this study area. Therefore, the most sustainable land management practice currently used in Tatkon Township is the sunflower-based 2 crops cropping system (L2).

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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