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Soil Health Assessment of the Manten Sub-Watershed Malang Regency Catchment Area

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ABSTRACT

This study was conducted in the Manten Sub-Watershed Catchment Area, Malang Regency, focusing on the districts of Bululawang, Tajinan, Wajak, and Poncokusumo. The research assessed three land use types—plantations, rice fields, and gardens—each represented by five sampling sites to capture the variation in land use across the region. Results revealed that garden soils exhibited superior chemical health compared to rice fields and plantations. Key soil limitations identified included low organic carbon content, cation exchange capacity (CEC), and base saturation (BS), all of which were found to restrict soil fertility in the study area. These findings highlight the urgent need for targeted soil management practices to enhance land productivity and promote sustainable agricultural practices in the region.

Keywords: soil chemical, watershed, catchment area, soil health, soil quality

INTRODUCTION

Land use changes that fail to incorporate soil and water conservation practices can exacerbate surface runoff and erosion during the rainy season (Yumansyah *et al*., 2021). Different land uses and cultivation methods have significant impacts on soil health and the sustainability of agricultural and forestry systems (Cuong *et al*., 2024; Mindari *et al*., 2024; Ibrahim *et al*., 2024; Karam *et al*., 2022). Conventional tillage practices can degrade soil properties by altering its physical, chemical, and biological characteristics. The catchment area plays a vital role within a watershed, as it encompasses sub-watersheds and smaller catchments that contribute to the flow of water. Rainwater collected in the catchment area moves through surface runoff, subsurface flow, and groundwater flow, ultimately converging in rivers that form the watershed (Gultom *et al*., 2022). Bound by ridges and the highest elevations of the region, the catchment area is essential for sustaining local water resources, as it is the source of springs that supply water to surrounding areas. The condition of the catchment area, particularly within a sub-watershed, directly influences the ecosystem and water availability. The Manten Sub-Watershed catchment area, covering 176 km² in Malang Regency, includes four districts: Bululawang, Poncokusumo, Tajinan, and Wajak.

Soil health refers to the soil's ability to create an optimal environment for plant growth, foster plant development, and support the activity of soil organisms (Simarmata *et al*., 2020; Aditya *et al*., 2021). The concept of soil health views soil as a living ecosystem, requiring careful management to restore and maintain its capacity to function effectively (Moebius-Clune *et al*., 2017). Managing soil health involves preserving suitable habitats for the diverse organisms that constitute the soil food web. This can be achieved by minimizing soil disturbance, diversifying plant species, maintaining live plants in the soil as much as possible, and ensuring that the soil is continuously covered.

The goal of this research is to assess the chemical health of the soil within the Catchment Area of the Manten Sub-Watershed in Malang Regency, providing crucial insights into soil conditions and guiding sustainable land management practices.

METHODOLOGY

Study site and soil sampling

This research was conducted in the catchment area of the Manten Sub-Watershed in Malang Regency, which spans four districts: Bululawang, Tajinan, Wajak, and Poncokusumo (**Figure 1**; **Table 1**). The selection of land unit sample points was based on an overlay of administrative maps, land use maps, and the Manten Sub-Watershed catchment area map. Using the overlay of the 1:70,000 scale land unit map, sampling points were identified. The study employed a survey method, focusing on three land uses: gardens, dry fields, and rice fields.

Soil sampling points were selected using a random sampling technique, with five replicates for each land use type (coded 1-5, as shown in **Table 1**). Soil samples were collected from two depth intervals: 0-30 cm and 30-60 cm. The samples were air-dried for 48 hours before being sieved. Soil analyses were performed at the Land Resources Laboratory of UPN "Veteran" East Java between February and April 2024. The analyses included organic carbon, cation exchange capacity (CEC), base saturation, total nitrogen (N-total), available potassium (K-available), available phosphorus (P-available), and soil pH.

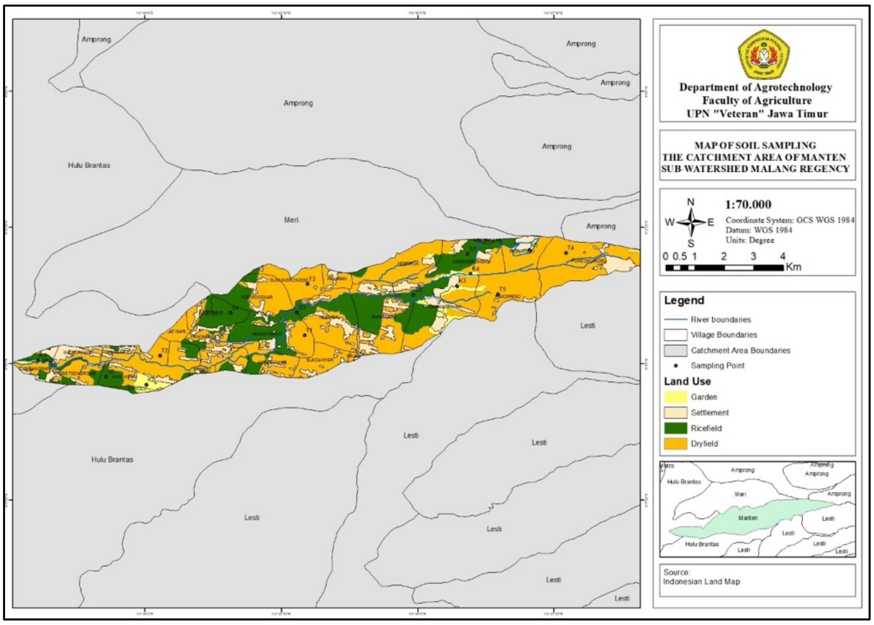

Figure 1. Map of soil sampling area

RESULTS AND DISCUSSION

Soil pH

Soil pH is a crucial factor in determining soil composition and overall health. It serves as an essential indicator of soil quality, influencing various biological and chemical processes that are vital to ecosystem function (Neina, 2019). According to Tedersoo *et al.* (2020), soil pH plays a significant role in regulating the activity and diversity of soil bacteria and fungi, which are key players in nutrient cycling and organic matter decomposition. When soil becomes excessively acidic, it can severely disrupt agricultural and forest ecosystems by inhibiting nutrient availability, limiting plant growth, and causing nutrient deficiencies due to the lowered pH. This makes soil pH a critical parameter for maintaining soil fertility and supporting sustainable land management practices.

Table 1. Code of sampling points

No	Code	Region/District	Land Use
1.	T_1	Wajak	Dryfield
2.	T_2	Tajinan	
3.	T_3	Tajinan	
4.	T_4	Poncokusumo	
5.	T_5	Poncokusumo	
6.	S_1	Poncokusumo	Ricefield
7.	S_2	Poncokusumo	
8.	S_3	Wajak	
9.	S_4	Tajinan	
10.	S_5	Bululawang	
11.	K_1	Bululawang	Gardens
12.	K_2	Bululawang	
13.	K_3	Poncokusumo	
14.	K_4	Poncokusumo	
15.	K_5	Poncokusumo	

Table 2. Result of pH value

Number	Land Unit	pH	Criteria
1	T_1	5.60	Slightly acidic
2	T_2	5.64	Slightly acidic
3	T_3	4.79	Higly Acidic
4	T_4	5.55	Acidic
5	T_5	4.00	Slightly acidic
6	S_1	5.67	Slightly acidic
7	S_2	6.14	Slightly acidic
8	S_3	5.60	Slightly acidic
9	S_4	5.52	Acidic
10	S_5	5.58	Acidic
11	K_1	6.43	Slightly acidic
12	K_2	6.29	Slightly acidic
13	K_3	5.24	Acidic
14	K_4	5.95	Slightly acidic
15	K_5	5.47	Acidic

Note: T=Dryfield; S=Ricefield; K=Garden

Based on the soil pH analysis (**Table 2**), the results show that land units T_1, T_2, S_1, S_2, S_3, K_1, K_2, and K_4 have pH values ranging from 5.5 to 6.29, placing them in the slightly acidic category. In contrast, land units T_3, T_4, S_4, S_5, K_3, and K_5 exhibit pH values between 4.79 and 5.58, which are considered acidic. Additionally, one land unit, T_5, recorded a pH of 4.0, classifying it as highly acidic. Overall, the pH values across the different land uses tend to fall within the slightly acidic range, as all values are below 7. Soil pH is closely linked to nutrient availability and absorption. When soil pH is in the optimal range of 6-7, nutrient absorption is most efficient, as this pH allows for the best uptake of essential nutrients by plants. At neutral pH levels, nutrients are more readily available in solution form, which supports better plant growth and fertility. Therefore, maintaining an appropriate soil pH is crucial for maximizing nutrient absorption and promoting healthy soil and plant development.

C-Organic

The research results indicate that organic carbon content varies across different land uses, with values fluctuating significantly within each land type. The highest average organic carbon content is found in garden land use, followed by dry fields and rice fields. Specifically, the average organic carbon values are 1.41% for gardens, 1.37% for dry fields, and 1.27% for rice fields (**Figure 2**). Garden land use exhibits higher organic carbon levels than the other land uses, likely due to denser and more diverse vegetation compared to the more monocultural dry fields and rice fields. Additionally, land management practices in garden areas, such as regular fertilizer application, may contribute to increased organic carbon content in the soil. In contrast, the relatively low organic carbon content in rice fields and dry fields may be attributed to intensive cultivation practices that deplete soil organic matter over time. Organic carbon, which originates from decomposed plant and animal matter, plays a crucial role in soil health. The type and amount of vegetation on the land directly influence organic carbon content, with higher levels of organic matter generally improving soil fertility. Organic matter enhances soil properties in several ways—chemically, physically, and biologically—making it a key factor in the success of agricultural systems (Syahrul *et al*., 2021).

Total nitrogen

Nitrogen (N) is a vital nutrient for plant growth, with its availability being most optimal in soils where pH exceeds 5.5. In more acidic soils, however, nitrification is inhibited, which reduces the availability of nitrate and forces plants to rely on ammonia as their primary nitrogen source. This shift can decrease nitrogen utilization efficiency (Zebarth *et al*., 2015). The results of this study show that the highest total nitrogen content is found in garden land use, with an average of 0.28%, and the highest individual value recorded at K_2 (0.38%) (**Figure 3**). The total nitrogen content at the research site ranges from 0.15% to 0.38%. These variations are influenced by multiple factors affecting the soil's nitrogen content. The average total nitrogen in dry fields is 0.23%, while in rice fields, it is slightly lower at 0.22%. Nitrogen bound in organic compounds is released through the decomposition of organic matter by soil microorganisms (Hou *et al*., 2019). Soil organic matter is considered the primary source of nitrogen, and land uses with higher organic matter content tend to have higher nitrogen levels (Khalif, 2018). One effective way to ensure an ongoing supply of nitrogen for plants is to maintain healthy, biologically active soils with ample reserves of decomposed organic matter. This approach supports long-term soil fertility and plant nutrition.

Available P

The available phosphorus (P) values in dry fields, rice fields, and garden land uses are generally categorized as high, as they exceed 40 ppm. However, in acidic soils, phosphate elements can become bound to aluminum (Al) and iron (Fe), reducing phosphorus availability. While most land uses in the study area show available P levels above 40 ppm, dry fields in particular exhibit some lower values, with T_3 (12.16 ppm) and T_5 (14.87 ppm) showing reduced availability due to the low pH of the soils. In contrast, land unit K_2 records the highest available P value at 76.98 ppm, likely due to its pH being above 6, which promotes optimal phosphorus availability. Maroeto *et al*. (2018) highlights that Al and Fe have a strong capacity to bind phosphorus in soils with pH levels below 6, significantly affecting phosphorus availability. The optimum pH for phosphorus availability is around 6.5.

Available phosphorus refers to the fraction of phosphorus in the soil that is readily accessible to plant roots. In phosphorus-rich soils, especially in areas with a history of inorganic phosphorus fertilizer use, phosphorus often accumulates in the soil's solid phase, where it is available for plant uptake (Ziadi *et al*., 2013). Phosphorus is a critical macronutrient for plants, playing essential roles in energy transfer, root development, and overall plant growth. While high phosphorus levels can indicate abundant availability, they also pose environmental risks, particularly through eutrophication when phosphorus is leached into water bodies. On the other hand, low phosphorus availability can limit plant growth. Excessive phosphorus application, especially near surface waters, on slopes, or in large quantities, can lead to environmental degradation, making phosphorus a potential contaminant. Overuse of phosphorus fertilizers in intensive agricultural systems has led to phosphorus accumulation in soils, which can subsequently be released into surface waters, causing eutrophication and damaging aquatic ecosystems (Van *et al*., 2017). Phosphorus supply will continue to play a critical role in the sustainability of agricultural production in the future.

Potassium

The laboratory analysis results reveal considerable variability in the available potassium (K) content across the study area in the catchment area of the Manten Sub-Watershed. The available K values range from a low of 0.32 me/100g to a high of 0.88 me/100g. Specifically, the values for different land units are as follows: T_1 at 0.35 me/100g (low), T_2 at 0.88 me/100g (high), T_3 at 0.37 me/100g (low), T_4 at 0.32 me/100g (low), and T_5 at 0.57 me/100g (medium) (**Figure 4**). The distribution of available K is somewhat fluctuating, with each point showing only modest differences within the respective land uses. Garden land consistently exhibits higher available K values across all sampling points. The highest average available K value was found in garden land, followed by dry fields, while rice fields showed the lowest values.

Available potassium refers to the form of potassium that plants can readily absorb and use for growth and development. According to Moebius-Clune *et al.* (2017), soil pH has a relatively minor effect on potassium availability, though potassium can be leached from sandy soils more easily and is weakly retained by organic matter. As a result, the application of potassium, based on the uptake needs of specific crops, is often necessary in such soils. Additionally, research by Liu *et al.* (2020) indicates that available potassium decreases as soil pH increases, further influencing the nutrient's availability for plant uptake.

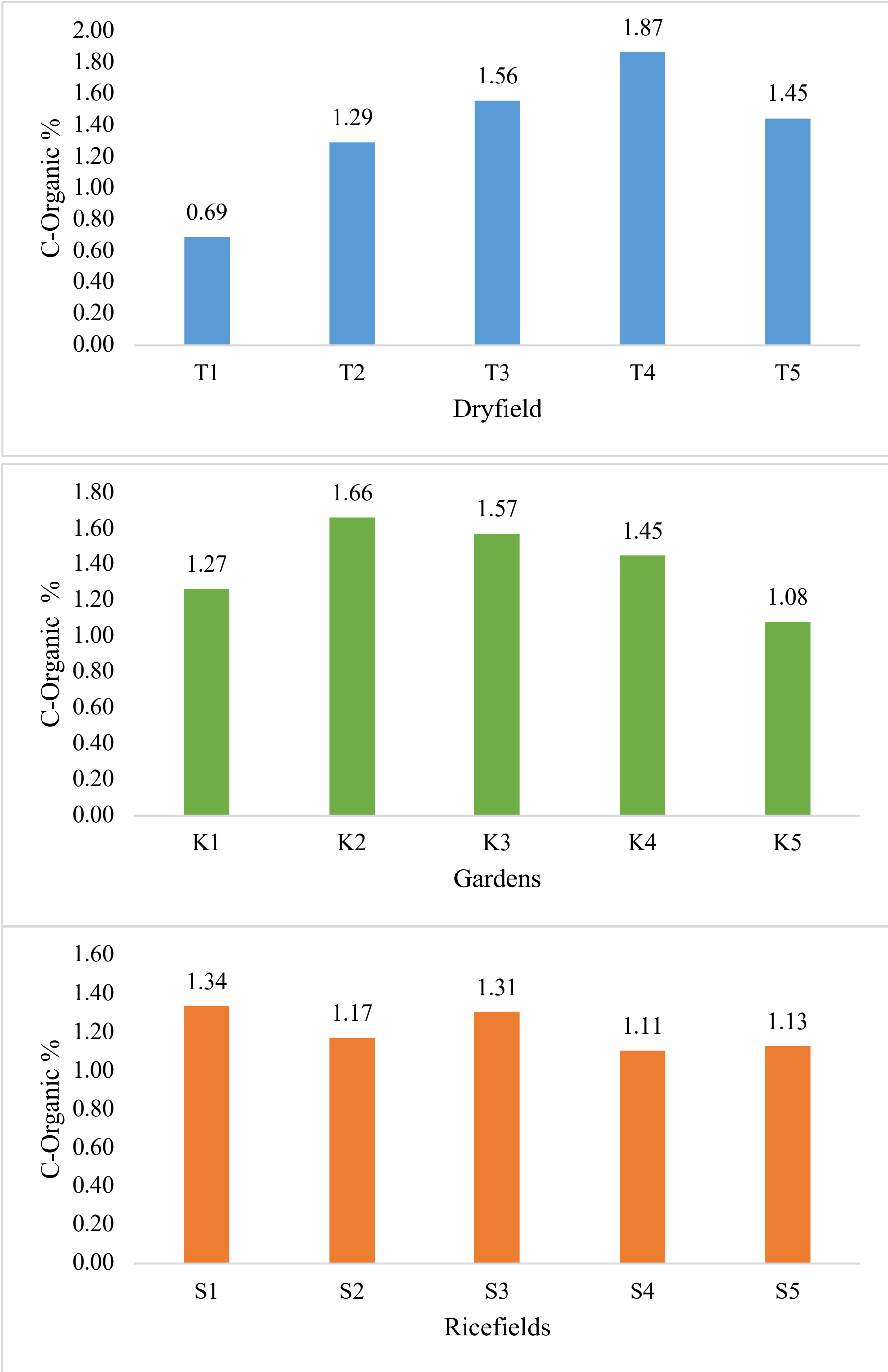

Figure 2. Result of C-Organic

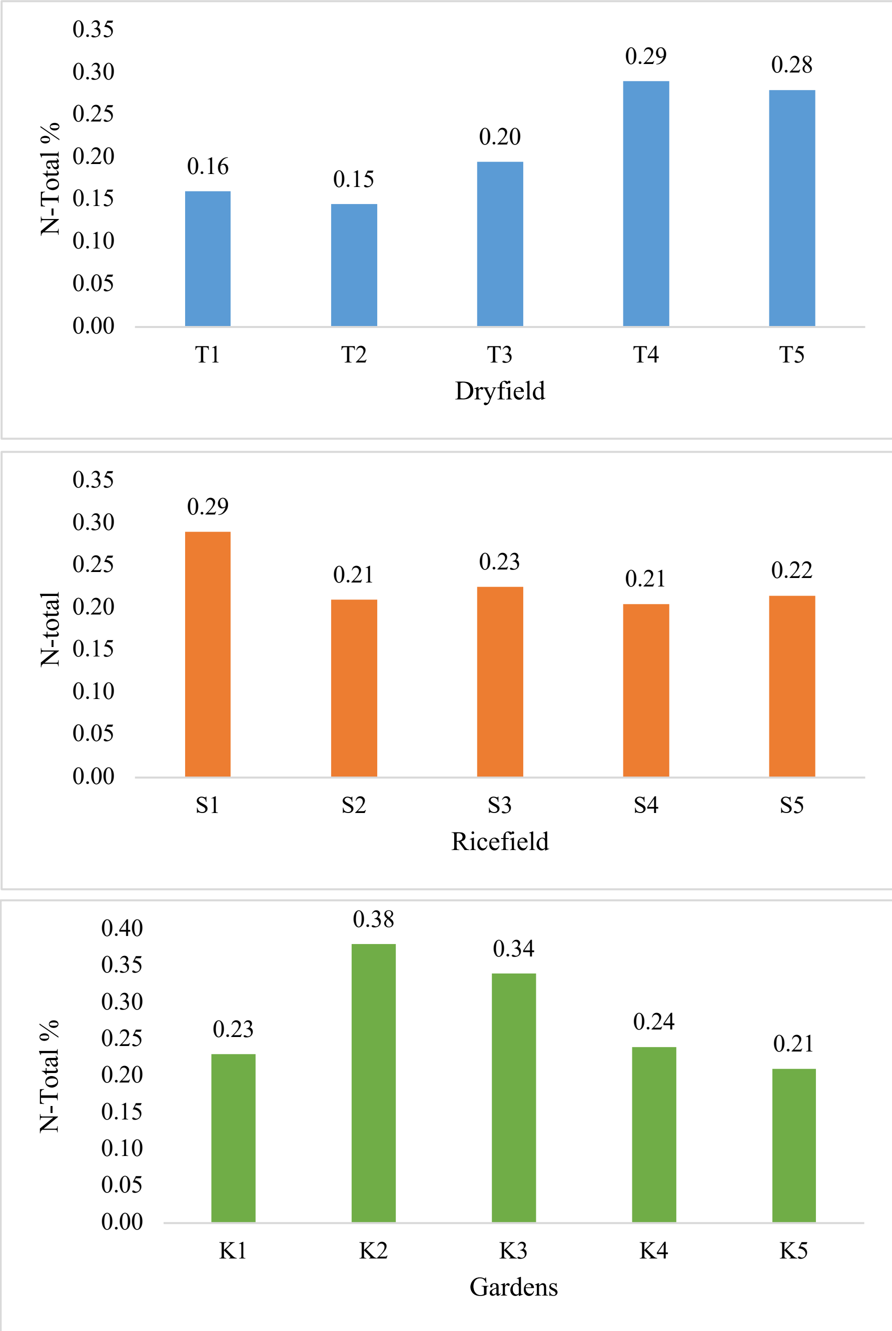

Figure 3. Result of total nitrogen

Table 3. Available P

Number	Land Unit	P-available
1	T1	19.26
2	T2	15.61
3	T3	7.16
4	T4	13.12
5	T5	9.87
6	S1	14.61
7	S2	13.89
8	S3	15.32
9	S4	22.68
10	S5	19.26
11	K1	29.20
12	K2	26.98
13	K3	28.67
14	K4	37.11
15	K5	21.22

Note: T=Dryfield; S=Ricefield; K=Garden

Cation exchange capacity (CEC)

The cation exchange capacity (CEC) of soil is influenced by its clay and organic matter content, with soils containing higher levels of clay and organic matter typically exhibiting higher CEC (Nursanti *et al*., 2023). The CEC values for the various land units in the study area are as follows: T_1 at 14.35 me/100g (low), T_2 at 20.25 me/100g (low), T_3 at 26.78 me/100g (medium), T_4 at 19.84 me/100g (low), and T_5 at 25.93 me/100g (medium) (**Figure 5**). In contrast, the paddy fields generally show moderate CEC values across all sampling points. For the garden plots, the CEC values range from moderate to high: K_1 at 30.14 me/100g (high), K_2 at 30.14 me/100g (high), K_3 at 20.71 me/100g (low), K_4 at 19.86 me/100g (low), and K_5 at 17.34 me/100g (low). The highest CEC values are found in K_1 and K_2, which are likely influenced by their higher organic matter content, contributing to their ability to retain cations more effectively.

Base saturation (BS)

The base saturation (BS) analysis results show significant variation across different land uses, with BS values at the research site ranging from 25.85% to 78.86% (**Figure 6**). In the dry fields, the BS values are as follows: T_1 at 42.54%, T_2 at 42.28%, T_3 at 33.52%, T_4 at 43.46%, and T_5 at 28.25%. Point T_5 exhibits the lowest BS value, which can be attributed to its low cation exchange capacity (CEC) and high acidity, leading to reduced base saturation. In the rice fields, the BS values for each point are: S_1 at 35.67%, S_2 at 4.12%, S_3 at 37.88%, S_4 at 56.22%, and S_5 at 34.13%. Like the dry fields, the base saturation in the rice fields is primarily classified as low to moderate, with significant fluctuations likely due to leaching processes and low pH levels.

Diao *et al.* (2023) suggests that low base saturation can impair the availability of essential nutrients like calcium and magnesium for plants. This is consistent with Husni *et al*. (2016), who noted that basic cations, including calcium and magnesium, are easily leached from the soil. A higher base saturation value indicates less leaching has occurred, which is beneficial for nutrient availability. Base saturation is also an important indicator of soil fertility: soils with base saturation >70% are considered highly fertile, those with BS between 51% and 70% are moderately fertile, and soils with BS <50% are classified as infertile (Winazira *et al*., 2021). Low base saturation values can result from leaching, and the percentage of base saturation is a key physico-chemical property that influences biological activity, soil structure, and nutrient reserves, making it a valuable index of soil fertility (Rawal *et al*., 2019).

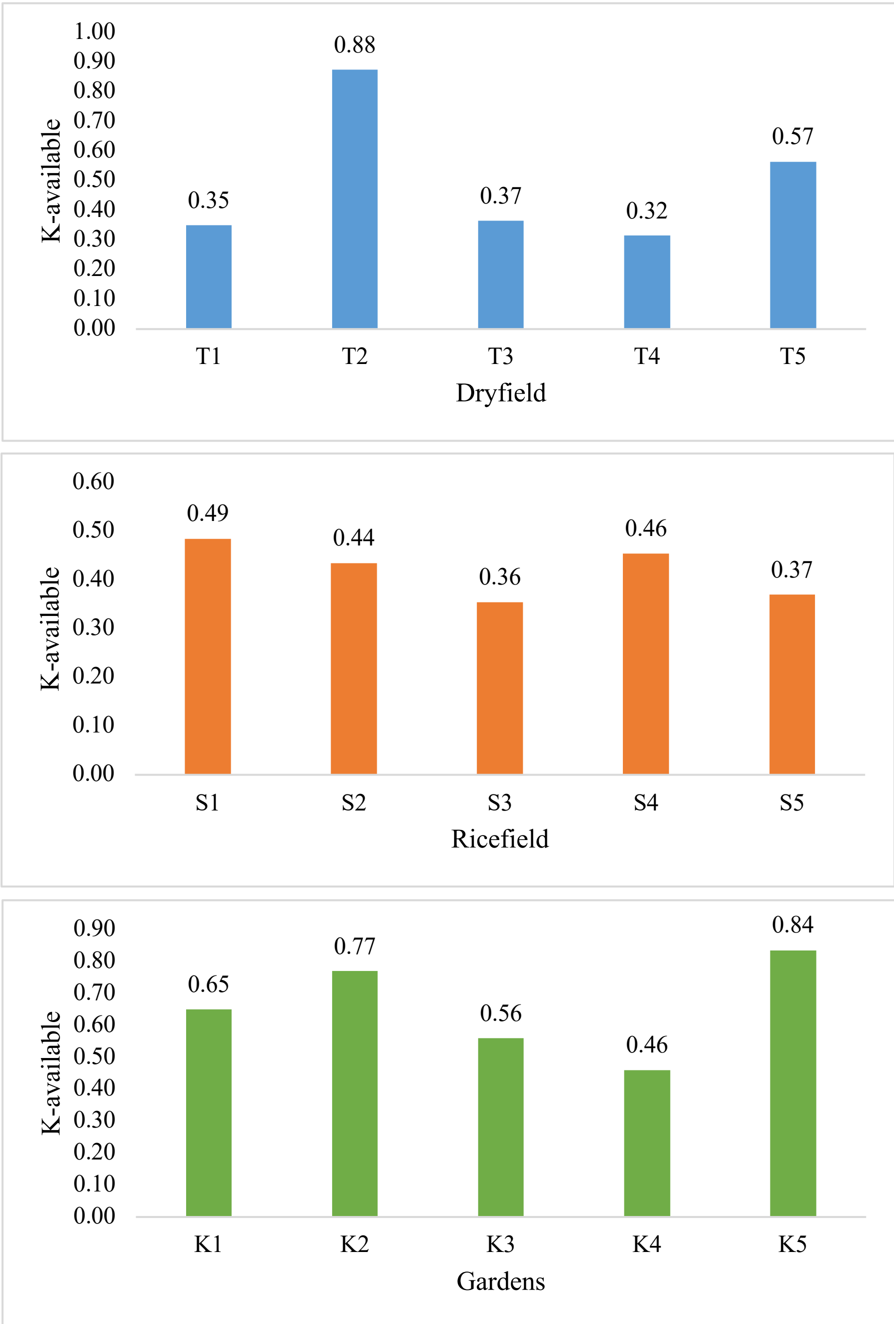

Figure 4. Potassium content

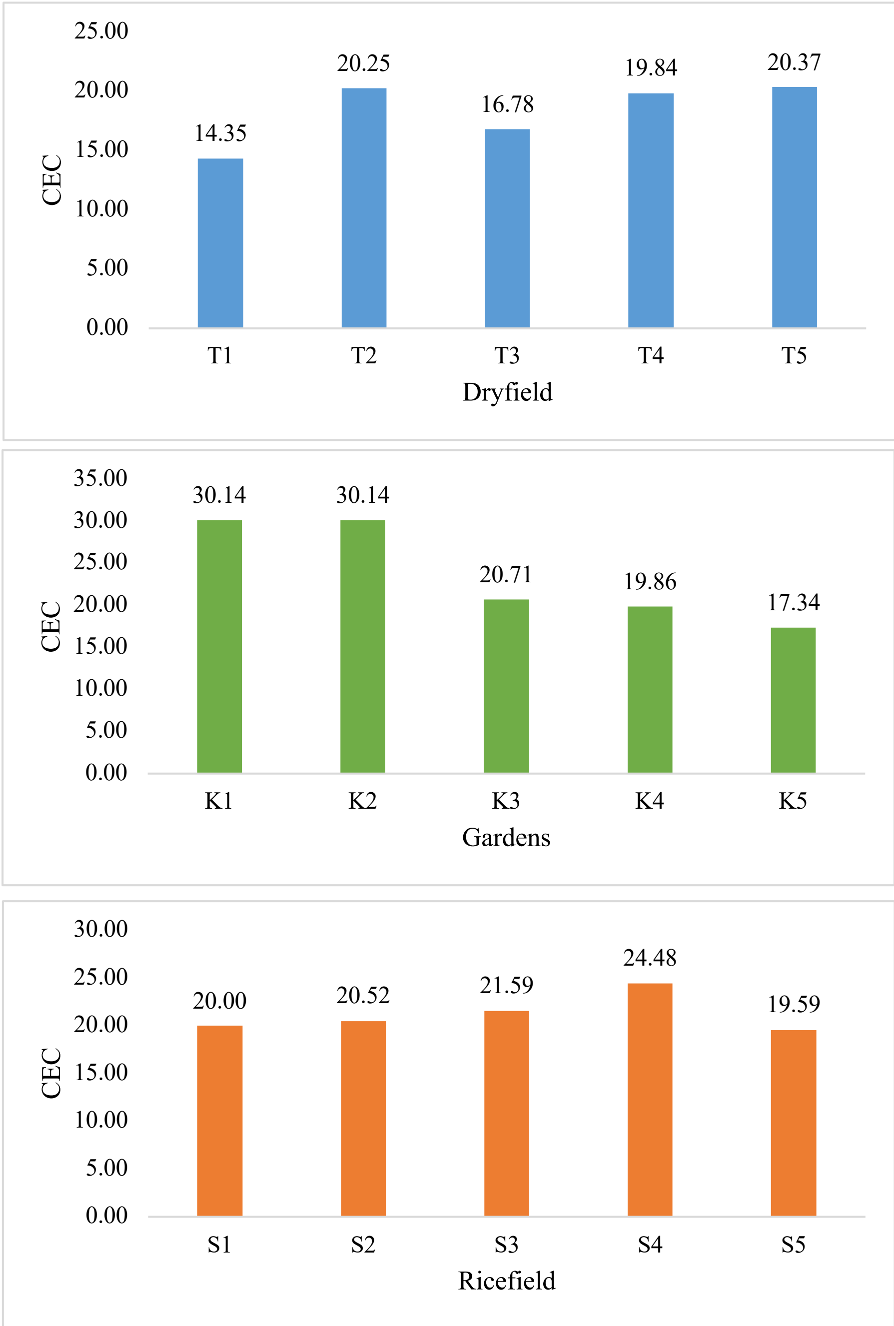

Figure 5. Cation exchange capacity

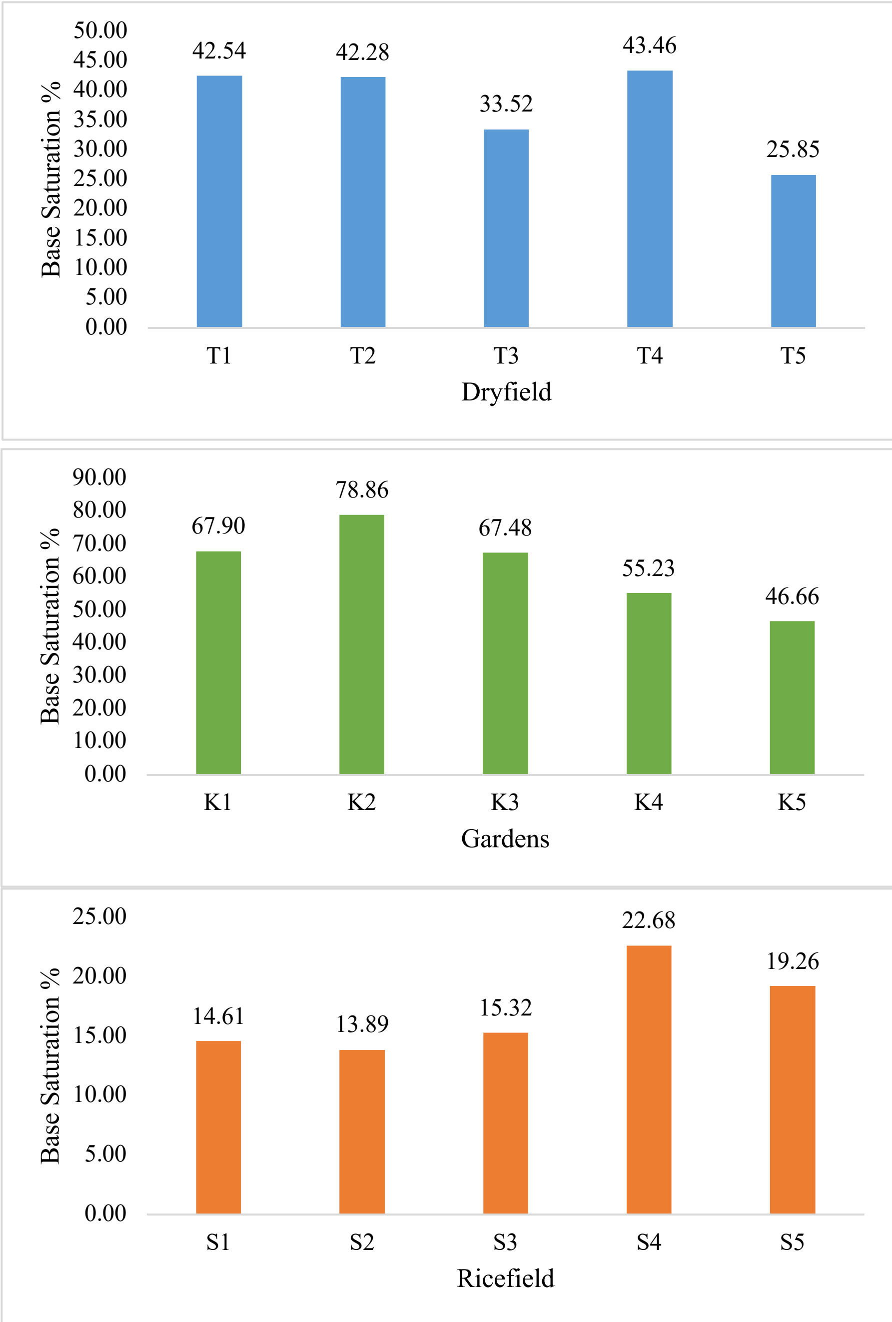

Figure 6. Base saturation

CONCLUSION

The chemical soil health status in the catchment area of the Manten Sub-Watershed, Malang Regency, indicates that garden land use maintains better soil health compared to rice and dry fields. Soil pH is generally slightly acidic, ranging from 5.5 to 6.29. However, the organic carbon content is consistently low, remaining below 2%, which limits soil fertility. To address these deficiencies, the application of organic amendments, including compost, manure, organic residues, biochar, and green manure, presents an effective strategy. These amendments will improve soil structure, increase organic matter, and enhance nutrient retention, ultimately fostering better soil fertility. Ongoing efforts to incorporate organic inputs are critical for restoring and sustaining soil health in the region, supporting both sustainable land management and enhanced agricultural productivity in the long term.

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REFERENCES

Aditya, H., Gandaseca, S., Rayes, M., Karam, D., Prayogo, C., & Nugroho, G. 2020. Characterization, changes in soil properties and vegetation distribution as affected by topography in Ayer Hitam Forest Reserve, Selangor, Peninsular Malaysia. *AGRIVITA Journal of Agricultural Science,* 42(3), 548-562.

Aditya, H.F., Gandaseca, S., Rayes, M.L., & Karam, D.S. 2021. Toposequent effect on soil morphology and slassification of Ultisol Soil in the Ayer Hitam Forest Reserve, Peninsular Malaysia. *Jurnal Sylva Lestari*, 9(2), 202–212.

Bashir, Z., Zargar, M.Y., & Vishwakarma, D.K. 2019. Potassium-solubilizing microorganisms for sustainable agriculture. In Applied Agricultural Practices for Mitigating Climate Change, 2, 17-28.CRC Press.

Chen, Y., Hou, D., He, Y., Huang, Q., & Kuzyakov, Y. 2022. Role of soil organic matter in soil potassium dynamics: A review. *Soil and Tillage Research*, 220: 113-120.

Cuong, L.V., Karam, D.S., Hung, B.M., Chau, M.H., & Quy, N.V. 2024. Variations in soil phosphorus levels in Acacia hybrid plantations across different ages in Southern Vietnam. *Malaysian Journal of Soil Science*, 28: 230-243.

Diao, M., Li, C., Li, J., & Zhao, Z. 2023. Effects of soil base saturation on soil nutrient content and nutrient availability. *Journal of Soil Science*, 74(2): 231-245.

Gultom, N., Badaruddin, B., & Kadir, S. 2022. Water discharge analysis in the watershed area of Barabai, Hulu Sungai Tengah District. *Jurnal Sylva Scienteae*, 5(5): 711-717.

Hou, E., Chen, C., McGrath, S.P., Zhao, F.J., Villas-Boas, S.G., & Shi, L. 2019. Soil organic matter-microbe interactions regulate carbon and nitrogen dynamics in agricultural soils. *Frontiers in Environmental Science*, 7(2): 180-185.

Husni, M.R., Sufardi, S., & Khalil, M. 2016. Evaluation of fertility status on several soil types in dry land of Pidie Regency, Aceh Province. *Scientific Journal of Agricultural Students,* 1(1): 147-154.

Ibrahim, M.H.M., Yunus, N., Abdu, A., Karam, D.S., Rajoo, K.S., Rani, R., Ibrahim, Z., Wahid, A.R.A., Abdullah M.A.A., Zulperi, D. & Johari, M.I.H. 2024. Soil quality assessment and climatic condition of selected forest reserves in Terengganu, Malaysia. *Malaysian Journal of Soil Science*, 28: 276-292.

Ichsan, M. 2022. Utilization of geographic information system for mapping water flow direction and watershed areas on national roads. Proceedings of KRTJ-HPJI. Pp: 1-7.

Karam D.S., Ibrahim, Z., Rani, R., Wahid, A.R.A., Kadir, Z.A., Salleh, M.S.A., Abdul-Hamid, H., Rajoo, K.S., Ibrahim, M.H.M., Azhar, M.A.A., Zulperi, D. & Abdu, A. 2022. A narrative review of the impact of forest rehabilitation programs on soil quality in Peninsular Malaysia. *Malaysian Journal of Soil Science*, 26: 1-16.

Khalif, U. 2018. The effect of Sengon (*Paraserianthes falcataria*) Plantation on soil C and N content in Resapombo Village, Doko, Blitar. *VIABEL: Scientific Journal of Agricultural Sciences,* 12(1): 49-59.

Liu. K.L., Han, T.F., Huang, J., Asad, S., Li, D.M., Yu, X.C., Huang, Q.H., Ye, H.C., Hu, H.W., Hu, Z.H., & Zhang, H.M. 2020. Links between potassium of soil aggregates and pH levels in acidic soils under long-term fertilization regimes. *Soil & Tillage Research,* 197:104480.

Maroeto, Priyadarshini, R., Siswanto, Idhom, M., & Santoso, W. 2022. Study on the potential of forest areas in aspects of land fertility in Wonosalam District, Jombang Regency. Seminar Nasional Agroteknologi Fakultas Pertanian UPN "Veteran" Jawa Timur 2021. NST Proceedings. Pp: 22-30.

Mindari, W., Chakim, M.G., Sasongko, P.E., Aditya, H.F., Karam, D.S., & Masri, I.N. 2024. The role of microclimate, vegetation variety and land use in the formation of humic substance. *Malaysian Journal of Soil Science*, 28:212-229.

Moebius-Clune, B.N., Moebius-Clune, B.K., Gugino, O.J., Idowu, R.R., Schindelbeck, A.J., Ristow, H.M., van Es, J.E., Thies, H.A., Shayler, M.B., McBride, K.S.M., Kurtz, D.W., Wolfe., & Abawi, 2017. Comprehensive Assessment of Soil Health, Third Edition. New York: Cornell University.

Neina, D. 2019. The role of soil pH in plant nutrition and soil remediation. *Applied and Environmental Soil Science*, 2019(1): 1-9.

Rasmussen, C., Heckman, K., Wieder, W. R., Keiluweit, M., Lawrence, C. R., Berhe, A. A., Blankinship, J.C., Crow, S.E., Druhan, J.L., Hick Pries C.E., Marin-Spiotta, E., Plante, A.F., Schadel, C., Schimel J.P., Sierra, C.A., Thompson, A., Wagai, R. 2018. Beyond clay: towards an improved set of variables for predicting soil organic matter content. *Biogeochemistry*, 137: 297–306.

Rawal, A., Chakraborty, S., Lic, B., Lewisd, K., Godoye, M., Paulettef, L., & Weindorf, D.C. 2019. Determination of base saturation percentage in agricultural soils via portable X-ray fuorescence spectrometer. *Geoderma,* 338:375–382.

Saifuddin, M.I.A., Fauzi, T., & Sudharmawan, A.A.K. 2023. The Effect of cover crops on soil quality in Gogo Rice planting in an effort to increase yield. *Journal Biologi Tropis,* 23(4): 299-306.

Shi, R.-y., Hong, Z.-n., Li, J.-y., Jiang, J., Baquy, M. A.-A., Xu, R.- k., & Qian, W. 2017. Mechanisms for increasing the pH buffering capacity of an acidic ultisol by crop residue-derived biochars. *Journal of Agricultural and Food Chemistry,* 65(37): 8111-8119.

Simarmata, T., Setiawati, M., & Herdiyantoro, D. 2020. Rapid Evaluation of Soil Health in Dryland Fields. Sumedang: Unpad Press.

Solly, E.F., Weber, V., Zimmermann, S., Walthert, L., Hagedorn, F., & Schmidt, M.W. 2020. A critical evaluation of the relationship between the effective cation exchange capacity and soil organic carbon content in Swiss forest soils. *Frontiers in Forests and Global Change,* 3(98):1-12.

Syahrul, S., Thaha, A.R., & Toana, M.R.C. 2021. Analysis of several soil chemical properties in various land use types in Tolai Barat Village, Torue Subdistrict, Parigi Moutong District. *AGROTEKBIS: Agricultural Science Journal,* 9(5): 1287-1297.

Tedersoo, L., Anslan, S., Bahram, M., Drenkhan, R., Pritsch, K., Buegger, F., & Abarenkov, K. 2020. Regional-scale in-depth analysis of soil fungal diversity reveals strong pH and plant species effects in Northern Europe. *Frontiers in Microbiology*, 11(1953): 1-31

Van der Salm, C., Van Middelkoop, J.C., & Ehlert, P.A.I. 2017. Changes in soil phosphorus pools of grasslands following 17 yrs of balanced application of manure and fertilizer. *Soil Use and Management,* 33(1): 2-12.

Wang, Z., Chen, H., & Yang, L. 2020. Contribution of soil cations to soil pH variation in agricultural systems. *Geoderma,* 55(1): 30-42.

Winazira, A., Ilyas, I., & Sufardi, S. 2021. Status and constraints of soil fertility in fallow lands and mixed gardens in Blang Bintang subdistrict, Aceh Besar district. *Scientific Journal of Agricultural Student,* 6(2): 79-87.

Yumansyah, A., Purwanto, M.Y.J., & Setiawan, Y. 2021. Conservation strategy for the catchment area of Ciliman Dam, Banten. *Journal of Natural Resources and Environmental Management,* 11(1): 152-164.

Zaman, M., Shahid, S.A., & Heng, L. 2019. Soil N-min management: A review. *Environmental Science and Pollution Research,* 26(26): 26445-26463.

Zebarth, B.J., Forge, T.A., Goyer, C., & Brin, L.D. 2015. Effect of soil acidification on nitrification in soil. *Canadian Journal of Soil Science,* 95:359–363

Ziadi, N., Whalen, J.K., Messiga, A.J., & Morel, C. 2013. Assessment and modeling of soil available phosphorus in sustainable cropping systems. *Advances in Agronomy,* 122: 85-126.