JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 10, Number 1 (October 2022):3787-3794, doi:10.15243/jdmlm.2022.101.3787
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Assessment of soil fertility using the soil fertility index method on several land uses in Tutur District, Pasuruan Regency of East Java

Purnomo Edi Sasongko[1,2*], Purwanto[3], Widyatmani Sih Dewi[3], Ramdan Hidayat[3]

[1] Doctoral Program of Agricultural Science, Graduate School Program of Sebelas Maret University, Jalan Ir. Sutami 36 A, Kentingan, 57126, Surakarta, Indonesia
[2] Department of Agrotechnology, Faculty of Agriculture, Universitas Pembangunan Nasional Veteran Jawa Timur, Jalan Raya Rungkut Madya 1, Gunung Anyar 60294. Surabaya, Indonesia
[3] Department of Soil Science, Faculty of Agriculture, Sebelas Maret University, Jalan Ir. Sutami 36 A, Kentingan, 57126, Surakarta, Indonesia

*corresponding author: purnomoedis@upnjatim.ac.id

Article history:
Received 24 March 2022
Accepted 8 July 2022
Published 1 October 2022

Keywords:
assessment
environment
land use
plantations
soil fertility index

Abstract

Changes in land use have an impact on the level of soil fertility. Soil management, such as land cover systems and the environment, are supporting factors. Assessment of soil fertility index using indicators of soil chemical properties such as organic C, availability of nutrients nitrogen (N), phosphorus (P), cation exchange capacity (CEC), and exchangeable cations (K, Ca, Mg, Na). The research was conducted in Tutur District, Pasuruan Regency, with a survey of 5 land uses, i.e., mixed crops, coffee plantations, apple plantations, vegetable fields, secondary forests, and conservation forests. Observations were made on elevation, slope, and vegetation. Parameters of physical properties measured were soil texture and aggregate stability. Observations of chemical properties included organic C, N, P, CEC, exchangeable cation (K, Ca, Mg, Na), and soil pH. Soil Fertility Index (SFI) data were analyzed using the Least Significant Difference method at a 5% level. The results showed the diversity of soil fertility levels obtained from the calculation of the soil fertility index. The soil fertility index value in 5 land uses in Tutur District ranged from 0.67 to 1.00. Coffee plantations had the highest SFI score of 1.00; this condition was supported by an organic C indicator of 6.21% and a CEC value of 39.12 cmol kg^{-1}. Conservation forest is the land use with the lowest SFI value of 0.67. The value of CEC and cation exchange in conservation forests are factors that impact the low value of SFI.

To cite this article: Sasongko, P.E., Purwanto, Dewi, W.S. and Hidayat, R. 2022. Assessment of soil fertility using the soil fertility index method on several land uses in Tutur District, Pasuruan Regency of East Java. Journal of Degraded and Mining Lands Management 10(1):3787-3794, doi:10.15243/jdmlm.2022.101.3787.

Introduction

The rapid increase in population and limited land resources are adequate for food production, and forest conversion into agricultural land, horticulture, and other arable lands cannot be avoided. The activities have led to the depletion of forest land. Conversion of forest land (conservation and secondary) and pasture to farmland can decrease rainfall or increase temperature, decrease soil productivity due to increased erosion, thereby decreasing soil fertility, changes in soil flora or fauna, and reduced soil organic matter, which plays an important role in maintaining soil quality, crop production, and environmental quality (Doran and Parkin, 1994; Spaccini et al., 2001; Kara and Bolat, 2008; Orobator, 2020). Land-use systems play an important role in influencing nutrient cycle and availability, moreover affecting biomass production (Lu et al., 2002). Soil fertility is important for sustainable agriculture. Tutur District is one of the central locations for various cultivated plants, ranging from horticultural crops to food crops. The land use varies, including mixed crops, coffee plantations, to the conservation forest of Bromo Tengger Semeru National Park. Differences in land use will affect the availability of nutrients in the soil and the quality of the soil (Takele et al., 2015). Human activities in land management are also the cause of changes in soil conditions (Chandrakala et al., 2018). Land management, mainly in soil organic matter (OM) management, affects soil fertility. The existence of organic matter is the key to supporting nutrient availability and maintaining soil quality (Rein et al., 2011), and being an agent in reducing the rate of soil quality decline (Zingore et al., 2011), being able to maintain the availability of soil nutrients to increase plant productivity (Singh and Singh, 2015).

Evaluation of soil fertility has provided information on managing land to support agricultural sustainability (Liao et al., 2015). Both assessments are carried out by analyzing soils that have different land management, so that management will be found that has an impact on soil fertility. Nutrient cycles in agroforestry systems are among the fastest when compared to others (Nair et al., 1995; Nair, 2007). The plant's part is decomposed by microbial activity, thus releasing nutrients into the soil and becoming available for plant uptake (Nair et al., 1995). The natural forest ecosystem of tropical forests is an undisturbed, efficient, and "closed" nutrient cycling system with relatively low nutrient loss or acquisition and high nutrient return. In contrast, most agricultural systems are "open" or "leaky" systems with relatively high nutrient loss.

Soil fertility can be monitored using a set of measurable attributes called indicators. These indicators can be broadly grouped as physical, chemical, and biological indicators and assess overall soil fertility indicators (Doran and Parkin, 1994; Ditzler and Tugel, 2002; Sahrawat and Narteh, 2006) and converted into soil fertility index. Comparing changes in soil properties due to changes in land cover is very important to understanding changes in soil and water quality, biodiversity, and the global climate system in natural resources and ecological processes (Houghton, 1994; Chen et al., 2001; Chaudhury et al., 2005; Abbasi et al., 2010).

This study aimed to measure changes in soil properties under conservation forest land conditions, vegetable plantations, apple plantations, coffee plantations, and mixed plantations by comparing them with soil properties beneath primary natural forests. Natural forests control changes in land use through changes in selected physicochemical and soil biology properties in research areas and establishing reciprocal relationships between soil fertility indexes and soil properties.

Materials and Methods

Soil sampling

The research area is located in Tutur District, Pasuruan Regency, Indonesia. The region receives an average rainfall of 3,072.3 mm with an average temperature of 26.3 °C. Coffee and apple plantations dominate land use in addition to the vegetable field in the region. The slope of the land varies from 8-45%. Cultivation is raindrops. According to USDA soil taxonomy, soils type in the study area is classified as Andisols and Inceptisols. Existing land-use systems used for this study were mixed crops, coffee plantations, apple plantations, vegetable fields, secondary forests, and conservation forests (Table 1).

Preparation and analysis of soil chemical properties

Soil samples were collected following standard procedures. The soil samples were air-dried and ground to pass through a 2 mm sieve. Combined glass calomel electrodes were used to determine the pH of the aqueous suspension (soil/solution ratio 1:2.5). Soil organic carbon (SOC) was determined using the wet destruction method of Walkley and Black (1934). Available phosphorus (P) was determined by the Olsen method (USDA and Committee, 2000). The cation exchange capacity (CEC) of the soil was determined according to the procedures developed by Rhoades (1983). Exchangeable cations (calcium (Ca), potassium (K), sodium (Na) and magnesium (Mg)) were extracted with 1 M of ammonium acetate (NH_4Oac pH 7.0) (Thomas, 1983). Potassium content was determined by flame photometry, while Ca and Mg were determined by titration of ethylene diamine tetra acetic acid (EDTA) (Tucker and Kurtz, 1961).

Calculation of Soil Fertility Index (SFI)

The SFI formula (Mukashema, 2007) was chosen because it represents the adequacy of the data on soil fertility indicators. The soil fertility index is considered the smallest collection of soil chemical properties that are best used to represent changes in soil fertility caused by humans. Soil fertility index (SFI) is very important to assess the individual variability of the most dynamic soil properties as an indicator of soil fertility. This index provides an explicit indication of soil fertility which cannot be easily discerned using individual soil properties. SFI is defined as the probability that all soil types with measured soil properties are in good fertile soil.

The SFI value varies from 0 to 1, which means from very low to very high soil fertility (Equation 1).

$0 \leq SFI \leq 1$ ……………………………………… (1)

Each MSFI is assigned a score equivalent to a very high probability for fertile soil (e.g., SFI=1) using the threshold and soil property class developed by Mutwewingabo and Rutunga (1987).

The number of class points to the probability assigned to each class (Equation 2):

$p_c = 1/n_c$ …………………………………….…..…… (2)

Where pc is the probability class c, and n is the number of classes.

The scoring (Sci) for each soil class depends on its position in the class range and pc (Equation 3):

$Sc_i = c_j \times p_c$ ……………………………..………. (3)

Where cj is the class number (1 to j) depending on the number of MSFI classes.

Table 1. Existing land-use systems used for this study.

Types of Land Use	Elevation (m)	Slope (%)	Coordinate	Location	Vegetation
T1 (Mixed crop)	570	8-20	7°48'07"S	112°48'18"E	*Albizia chinensis, Ceiba pentandra, Zea mays, Syzygium aromaticum, Manihot esculenta, Durio zibethinus*
T2 (Coffe plantation)	788	10-25	7°50'15"S	112°48'47"E	*Coffea canephora*, *Leucaena leucocephala, Albizia chinensis, Azadirachta indica, Syzygium aromaticum, Pennisetum purpureum, Musa paradisiaca*
T3 (Apple plantation)	928	20-35	7°52'43"S	112°49'41"E	*Pyrus malus*, *Bambusoideae, Albizia chinensis, Brassica oleracea var. botrytis*
T4 (Vegetable field)	990	16-20	7°53'02"S	112°48'40"E	*Lycopersicum esculentum, Brassica oleracea* var. botrytis, *Brassica rapa subsp. pekinensis*, *Capsicum annum, Daucus carota*
T5 (Secondary forest)	1019	20-45	7°54'84"S	112°50'39"E	*Calliandra, Casuarina junghuhniana, Albizia chinensis, Polypodiophytina, Eupatorium odoratum, Pennisetum purpureum*
T6 (Conservation forest)	1365	20-40	7°55'01"S	112°59'28"E	*Casuarina junghuhniana, Hibiscus tiliaceus, Ageratum conyzoides, Polypodiophytina, Eupatorium odoratum*

Remarks: T1 = Mixed Crop, T2 = Coffee Plantation, T3 = Apple Plantation, T4 = Vegetable Field, T5 = Secondary Forest, T6 = Conservation Forests.

The combined indicator scores are used to obtain a single index value that reflects the soil fertility index (SFI) of each sample location. The SFI is an additive index and is obtained by adding up the scores for each soil fertility indicator, divided by the number of indicators, and then multiplied by 10 (Equation 4):

$SFI = \frac{\sum_{i=1}^{n} Sci}{N} \times 10$ …...…………….……………. (4)

where Sci is the MSFI indicator score and N is the number of MSFI indicators. Data are multiplied by 10 to give index values from 1 to 10.

Table 2. The values of the soil fertility index and the corresponding fertility classes.

Fertility Index Value	Fertility Class
0.00-0.25	Very Low (VL)
0.25-0.50	Low (L)
0.50-0.75	Moderate (M)
0.75-0.90	High (H)
0.90-1.00	Very High (VH)

Source : Bagherzadeh et al. (2018)

The calculation of the soil evaluation factor refers to the calculation model of Lu et al. (2002) with the following equation:

$$SEF = [\text{exch-K (cmol kg}^{-1}\text{, dry soil)} + \text{exch-Ca (cmol kg}^{-1}\text{, dry soil)} + \text{exch-Mg (cmol kg}^{-1}\text{, dry soil)} \log(1 + \text{exch-Al (cmol kg}^{-1}\text{, dry soil))}] \times \text{SOM (\%, dry soil)} + 5 \quad ..(5)$$

Results and Discussion

Soil physical and chemical properties

The pH value of the soil varies from high to low, which was 5.78 in forest land, followed by apple plantations, secondary forests, vegetable fields, and mixed forests, and the lowest pH is 5.01 in the coffee plantation. Conservation forest land-use systems show the greatest pH among other lands, which can be attributed to the safety of exchangeable bases loss. The amount of land cover will reduce the destructive energy from rainwater, thereby reducing the loss of dissolved nutrients. Nutrient leaching causes the soil to lose available nutrients, such as a decrease in exchangeable cations (Sardiana et al., 2017). If the land is opened for cultivation business needs, then the rainfall that falls on the land will bring soil material along with nutrient nutrients in it, so that the availability of alkaline bases decreases. The next impact on the decrease in soil pH is that the apple garden soil has a rather high soil pH, which makes it possible that there is additional agricultural lime that serves to remodel excess nitrogen due to the provision of excess N fertilizer that is generally applied by farmers. The canopy of the apple plantation is classified as lusher than the vegetable field and mixed crop so that nutrient loss can be reduced.

The coffee and apple plantations have sufficient available N and P, T2 (0.65% total N and 28.88 mg kg^{-1} available P) and T3 (0.50% total N and 42.36 mg kg^{-1} available P). However, the availability of nutrients in the vegetable field is very low (Table 2). This is supported by the condition of the land, which tends to be open without land cover. Harvesting crop residues is also carried out, thereby reducing the supply of organic carbon in the soil. The low available-P value is related to the organic carbon content of the soil (Khadka et al., 2018). The management of both intensive fields is made by providing inorganic fertilizers to increase the availability of N and P. Soil organic C affects the availability of nutrients such as nitrogen, phosphorus, and cation exchange capacity (Ibrahim, 2017). Coffee plantations are also given organic fertilizers to maintain nutritional balance, although it ultimately impacts the soil pH. The soil pH value also influences the availability of soil nutrients (Ibrahim, 2017). The supply of organic C and nutrients such as nitrogen (N) is also affected by the land cover which is used as a shade plant for coffee plants (Maina et al., 2000).

Table 3. Soil chemical properties at different land use.

Types of Land Use	pH	SOC	Tot-N	Av-P	CEC	Exch-K	Exch-Ca	Exch-Na	Exch-Mg
		(%)		mg kg^{-1}			cmol kg^{-1}		
T1	5.29 ab	1.16 a	0.30 a	16.23 ab	23.79 b	0.73 b	5.68 a	1.54 ab	0.61 a
T2	5.01 ab	6.21 e	0.65 d	28.88 c	39.19 d	1.42 c	8.43 b	1.09 ab	1.16 b
T3	5.71 b	2.26 c	0.50 c	42.36 d	39.52 d	1.35 c	8.10 b	1.02 b	1.16 b
T4	5.34 ab	1.86 b	0.42 bc	19.16 b	32.07 c	0.62 b	7.25 b	1.58 ab	1.19 b
T5	5.48 b	2.32 c	0.40 b	32.18 c	31.69 c	0.59 b	6.90 a	1.14 ab	1.57 b
T6	5.78 b	2.91 d	0.44 bc	9.68 a	17.67 c	0.17 a	5.26 a	0.18 a	0.91 ab
LSD	±0.34	±0.31	±0.08	±7.98	±3.17	±0.27	±1.35	±0.79	±0.49

Notes: Numbers followed by the same letters in the same column indicate no significant difference in the Least Significant Difference (LSD) test level of 5%. T1 = Mixed Crop, T2 = Coffee Plantation, T3 = Apple Plantation, T4 = Vegetable Field, T5 = Secondary Forest, T6 = Conservation Forests. SOC = soil organic carbon, Tot-N = total N, Av-P = available P, Exch. = exchangeable.

Soil physical factors also determine the N and P content in the soil. Aggregate stability is also important to maintain the ability to hold water in the soil. Soil aggregates are also affected by the presence of soil organic carbon content; if the content is low, the stability of soil aggregates will be disturbed (Liu et al., 2010). Soil with a sandy texture is easier to lose nutrients through the washing process (Khattak and Hussain, 2007) when compared to soil with a loamy or clay texture. Soil conditions with low land cover are also contributing factors to soil nutrient loss. The presence of soil organic matter will undergo rapid decomposition (Guillaume et al., 2016). Rapid changes in organic carbon cause the soil to lose its carbon content, which plays a role in maintaining the availability of soil nutrients. The value of exchangeable cations at different land uses showed (Table 2) significantly different results with the LSD test at 5%. This condition shows that the influence of land management has an impact on the difference in exchangeable cation content. The highest exchangeable cation content was seen in the land use of coffee (T2) and apples (T3). Clay soil texture conditions have an influence on the availability of potassium (K) nutrients compared to soils with loamy and sandy textures (Khattak and Hussain, 2007). Coffee land use with silty clay loam texture (Table 3) has a higher exchangeable K content than other land uses. Exchangeable K and exchangeable Ca have the highest rates in coffee and apple plantations (Table 3); this is equivalent to the value of soil CEC. Both of these cations are needed by plants in macro quantities by plants, so their existence is expected. Soil Na level is present in a small amount, possible from the addition of fertilizers or mineralization of the parent material. Agricultural activities such as fertilization, tillage, composting, and manure have an impact on soil fertility (Brevik and Hartemink, 2010). The availability of K, Ca, Mg, and Na nutrients in apple plantations from the application of organic and chemical fertilizers. Soil physical properties in several land uses have different characteristics. The land use has classes from clayey texture, silty clay loam, and silty loam. Land management has an impact on changes in soil physical properties, including the stability of soil aggregates that change due to tillage (Liu et al., 2010). The distribution of soil fraction values, namely sand, silt, and clay, plays a very important role in supporting the level of soil fertility. The highest clay fraction content was in mixed garden land use (T1) and coffee plantations (T2). The clay fraction has a role in providing available N, P, and K nutrients in the soil (Kome et al., 2019). The clay fraction is a place for the exchange of nutrients exchangeable such as K, Ca, Mg and Na, thus supporting the maintenance of soil fertility.

Table 4. Soil physical properties at different land use.

Types of Land Use	Aggregate stability		Sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture
	WSA (%)	Criteria					
T1	82.71	High	6	5	33	56	Clay
T2	70.66	High	6	6	52	36	Silty clay loam
T3	87.46	High	6	11	66	17	Silty loam
T4	58.15	High	7	10	72	11	Silty loam
T5	82.01	High	6	8	68	18	Silty loam
T6	82.58	High	15	10	59	16	Silty loam

Notes: T1 = Mixed Crop, T2 = Coffee Plantation, T3 = Apple Plantation, T4 = Vegetable Field, T5 = Secondary Forest, T6 = Conservation Forests, WSA = water-stable aggregates.

Although the level of clay in a mixed crop is high, the value of CEC is not only influenced by clay levels (Sardiana et al., 2017), but organic matter also plays a high role (Ibrahim, 2017). Coffee plantations have become a reference for good land management because they can maintain the stability of nutrients and groundwater governance. Soil organic matter content has a role in increasing the stability of soil aggregates, thereby reducing nutrient losses from the soil (Gwenzi et al., 2009). The distribution of roots in a coffee plantation will add air content to the soil to improve the infiltration and percolation of water into the soil. The difference in exchangeable cations values is the impact of land management systems, deforestation, leaching, and crop residues are supporting factors (Takele et al., 2015).

Assessment of soil fertility index at different land uses

Changes in land use are a factor in the diversity of soil fertility conditions in the Tutur District. Soil fertility assessment will be a reference in land management to maintain a sustainable agricultural system. Assessment of soil fertility can be done through fertility indicators which are calculated into a soil fertility index. Soil fertility index (SFI) in several different land uses shows criteria with a range of medium to very high (Table 5). SFI values with very high criteria are shown for coffee plantations (1.00) and apples (0.91). Other high values were indicated by mixed crops (0.76), vegetable fields (0.82), secondary forest (0.87), and the medium value of conservation forest (0.67).

Table 5. The results of an assessment of the soil fertility index.

Types of Land Use	Soil Fertility Index (SFI)	Criteria*	Soil Evaluation Factor (SEF)
T1	0.76	High	12.02
T2	1.00	Very high	16.01
T3	0.91	Very high	15.61
T4	0.82	High	14.06
T5	0.87	High	14.06
T6	0.67	Moderate	11.35
Average	0.84		13.85

Notes: T1 = Mixed Crop, T2 = Coffee Plantation, T3 = Apple Plantation, T4 = Vegetable Field, T5 = Secondary Forest, T6 = Conservation Forests. *criteria based on Bagherzadeh et al. (2018).

Soil fertility indicators have various effects on the soil fertility index indicated by the R^2 value. The regression value of each indicator shows the effect of changes in the value of the soil fertility index. Soil P availability shows R^2=0.7904 with an understanding of the effect of 79.04% P availability on the SFI value (Figure 1). The best regression is shown by the cation exchange capacity (CEC) R^2=0.8639, Exch-K R^2=0.7797, Exch-Ca R^2=0.7278. The condition of low regression value was indicated by total-N R^2=0.4046 and organic C R^2=0.4726. Referring to the parameter indicators, the SFI value is influenced by the ability of cation exchange capacity and base cations in the soil (Mukashema, 2007; Bagherzadeh et al., 2018). Cation exchange capacity (CEC) has an impact on nutrient uptake in the soil, so it has a significant influence on the value of the soil fertility index. Soil fertility index can be used as a reference in land management. Changes in soil fertility indicators will have an impact on human activities, including agriculture, animal husbandry, and management policy-making by the government (Tilahun, 2007).

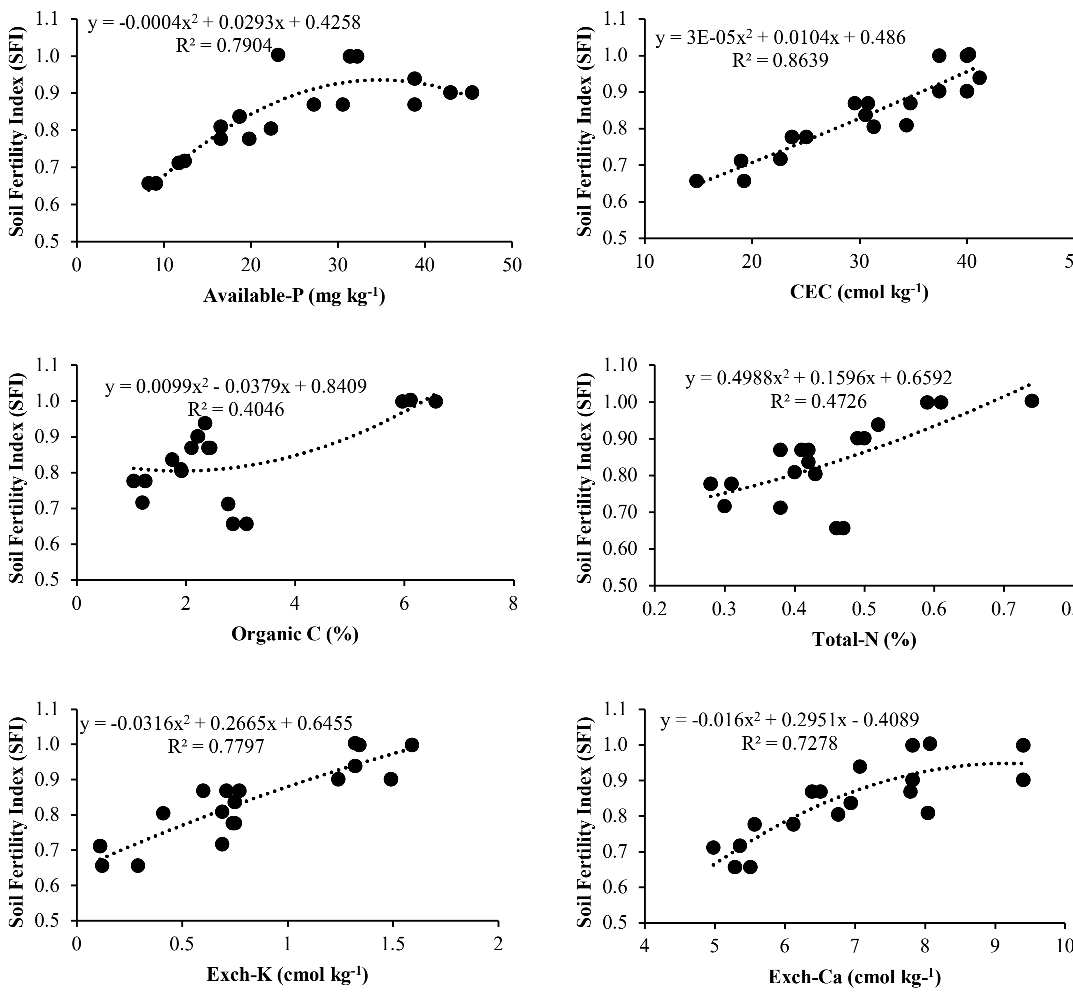

Figure 1. The relationship between parameter indicators and soil fertility index.

The soil fertility index value of coffee plantations is the highest, with a value of 1.00, due to intensive management and agricultural systems prioritizing the supply of nutrients from organic matter. Fertilization using animal manure is an alternative to increase the availability of nutrients (N, P, and K) and soil organic carbon (Singh and Singh, 2015). The presence of soil organic matter is the key to soil fertility in land management (Bagherzadeh et al., 2018). The SFI value of conservation forest is classified as a medium; it is suspected that topography is one of the causes of the slope (20-40%). The influence of the slope will have an impact on the leaching of soil organic matter on the surface (Zádorová et al., 2011). Cropping patterns also influence the level of soil fertility through land cover and plant leaf litter. Coffee plantations have complex land cover systems ranging from grasses to legumes. The supply of organic carbon and nitrogen in coffee plantations is supplied through land cover systems that serve as shade plants Maina et al., 2000). Different systems with land use for cultivation, such as apple plantations, mixed crops, and vegetable fields, tend to be open. Nutrient supply in apple plantations is obtained from the use of inorganic fertilizers to provide N, P, and K supplies (Khattak and Hussain, 2007). Fertilization is intended to increase plant productivity and the quality of apples.

Land management is very important to maintain the level of soil fertility because it will have an impact on the production and quality of agricultural products. The choice of a management system is needed to maintain the availability of macronutrients and micronutrients, increasing organic carbon and cation exchange capacity. The availability of organic matter and CEC is the key to assessing soil fertility because of their impact on the availability of nutrients and groundwater. It is also supported by the physical properties of the soil that can support the ability of the soil to provide nutrients and groundwater.

Conclusion

Changes in land use and different land management show different levels of fertility. These conditions are influenced by environmental factors such as slopes, cropping patterns, and land cover systems. Factors of physical and chemical properties become indicators of assessment using the soil fertility index method. Land use for coffee and apple plantations showed the highest soil fertility index values with values of 1.00 and 0.91. Coffee plantation land management has an impact on the value of nutrient availability (N, P, K), CEC, and exchangeable cations best when compared to other land uses. The land use of apple plantations, vegetable fields, and mixed crops has an SFI value with very high to high criteria. Secondary forest and conservation forests have high to moderate SFI values. Natural forest management impacts a sustainable system even though it has a lower SFI value than others.

Acknowledgements

The authors would like to thank the Ministry of Research, Technology and Higher Education for providing research fund, and the Head of the Department of Soil Science and Land Resources Faculty of Agriculture, the UPN Veteran of East Java, for the permission to use the laboratory for soil analysis, as well as soil science students from the agrotechnology study program for their generous help to carry out this study

References

Abbasi, M.K., Zafar, M. and Sultan, T. 2010. Changes in soil properties and microbial indices across various management sites in the mountain environments of Azad Jammu and Kashmir. *Communications in Soil Science and Plant Analysis* 41(6):768-782, doi:10.1080/00103620903565985.

Bagherzadeh, A., Gholizadeh, A. and Keshavarzi, A. 2018. Assessment of soil fertility index for potato production using integrated fuzzy and AHP approaches, northeast of Iran. *Eurasian Journal of Soil Science* 7(3):203-212, doi:10.18393/ejss.399775.

Brevik, E.C. and Hartemink, A.E. 2010. Early soil knowledge and the birth and development of soil science. *Catena* 83(1):23-33, doi:10.1016/j.catena.2010.06.011.

Chandrakala, M., Ramesh, M., Sujatha, K., Hegde, R. and Singh, S.K. 2018. Soil fertility evaluation under different land use system in tropical humid region of Kerala, India. *International Journal of Plant & Soil Science* 24(4):1-13, doi:10.9734/ijpss/2018/40099.

Chaudhury, J., Mandal, U.K., Sharma, K.L., Ghosh, H. and Mandal, B. 2005. Assessing soil quality under a long-term rice-based cropping system. *Communications in Soil Science and Plant Analysis* 36(9-10):1141-1161, doi:10.1081/CSS-200056885.

Chen, L., Wang, J., Fu, B. and Qiu, Y. 2001. Land-use change in a small catchment of northern Loess Plateau, China. *Agriculture, Ecosystems and Environment* 86(2):163-172, doi:10.1016/S0167-8809(00)00271-1.

Ditzler, C.A. and Tugel, A.J. 2002. Soil quality field tools. *Agronomy Journal* 94(1):33-38, doi:/10.2134/AGRONJ2002.3300.

Doran, J.W. and Parkin, T.B. 1994. Defining and Assessing Soil Quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F. and Stewart, B.A. (eds.), *Defining Soil Quality for a Sustainable Environment*, *Soil Science Society of America Journal*, Madison, 3-21, doi:10.2136/sssaspecpub35.c1.

Guillaume, T., Maranguit, D., Murtilaksono, K. and Kuzyakova, Y. 2016. Sensitivity and resistance of soil fertility indicators to land-use changes: New concept and examples from conversion of Indonesian rainforest to plantations. *Ecological Indicators* 67(2016):49-57, doi:10.1016/j.ecolind.2016.02.039.

Gwenzi, W., Gotosa, J., Chakanetsa, S. and Mutema, Z. 2009. Effects of tillage systems on soil organic carbon dynamics, structural stability and crop yields in irrigated wheat (*Triticum aestivum* L.)-cotton (*Gossypium hirsutum* L.) rotation in semi-arid Zimbabwe. *Nutrient Cycling in Agroecosystems* 83(3):211-221, doi:10.1007/s10705-008-9211-1.

Houghton, R.A. 1994. The worldwide extent of land-use change: In the last few centuries, and particularly in the last several decades, the effects of land-use change have become global. *BioScience* 44(5):305-313.

Ibrahim, J. 2017. Assessment of soil physical and chemical properties under vegetable cultivation in Abuja metropolitan area, Nigeria. *Zaria Geographer* 24(1):89-99.

Kara, Ö. and Bolat, I. 2008. The effect of different land uses on soil microbial biomass carbon and nitrogen in Bartin Province. *Turkish Journal of Agriculture and Forestry* 32(4):281-288, doi:10.3906/tar-0711-13.

Khadka, D., Lamichhane, S., Bhurer, K.P., Chaudhary, J.N., Ali, M.F. and Lakhe, L. 2018. Soil Fertility Assessment and Mapping of Regional Agricultural Research Station, Parwanipur, Bara, Nepal. *Journal of Nepal Agricultural Research Council* 4(April):33-47, doi:10.3126/jnarc.v4i1.19688.

Khattak, R.A. and Hussain, Z. 2007. Evaluation of soil fertility status and nutrition of orchards. *Soil & Environment* 26(1):22-32.

Kome, G.K., Enang, R.K., Tabi, F.O. and Yerima, B.P.K. 2019. Influence of clay minerals on some soil fertility attributes: a review. *Open Journal of Soil Science* 09(09):155-188, doi:10.4236/ojss.2019.99010.

Liao, W., Tang, D., Wang, X. and Cheng, X. 2015. Soil quality status of different land-use types in Shiqu County, China. *International Symposium on Energy Science and Chemical Engineering* (ISESCE 2015), doi:10.2991/isesce-15.2015.27.

Liu, X.L., He, Y., Zhang, H.L., Schroder, J.K., Li, C.L., Zhou, J. and Zhang, Z.Y. 2010. Impact of land use and soil fertility on distributions of soil aggregate fractions and some nutrients. *Pedosphere* 20(5):666-673, doi:10.1016/S1002-0160(10)60056-2.

Lu, D., Moran, E. and Mausel, P. 2002. Linking Amazonian secondary succession forest growth to soil properties. *Land Degradation and Development* 13(4):331-343, doi:10.1002/ldr.516.

Maina, J.M., Mburu, M.W.K., Mureithi, J.G., Gachene, C.K.K., Mburu, J.N., Ngugi, J.N. and Kimemia, J.K. 2000. Evaluation of Legumes as Cover Crops for Soil and Weed Management in Smallholder Coffee Cropping Systems in Central. https://www.yumpu.com/en/document/view/9193893/evaluation-of-legumes-as-cover-crops-for-soil-kenya-agricultural-.

Mukashema, A. 2007. Mapping and Modelling Landscape-based Soil Fertility Change in Relation to Human Induction Case study: GISHWATI Watershed of the Rwandan highlands. Master of Science thesis, ITC-Netherlands.

Mutwewingabo, B. and Rutunga, V. 1987. Study of the soils of the PIA project test stations located in Mwogo, Gitarama, Kaduha and the Akanyaru Valley. MINAGRI-PIA, Kigali (*in French*).

Nair, P.K.R. 2007. Agroforestry for sustainability of lower-input land-use systems. *Journal of Crop Improvement* 19(1-2): 25-47, doi:10.1300/J411V19N01.

Nair, P.K.R., Kang, B.T. and Kass, D.C.L. 1995. Nutrient Cycling and Soil-Erosion Control in Agroforestry Systems. Agriculture and Environment: Bridging Food Production and Environmental Protection in Developing Countries, 117-138, doi:10.2134/ASASPECPUB60.C7.

Rein, A., Legind, C.N., and Trapp, S. 2011. *New concepts for dynamic plant uptake models*, 14th International Workshop on Quantitative Structure-Activity Relationships in Environmental and Health Science (QSAR2010) – Part 2. *22*(1–2), 191-215. doi:10.1080/1062936X.2010.548829.

Rhoades, J.D. 1983. Cation exchange capacity. In: Page, A.L. (ed.), *Method of Soil Analysis,* doi:10.1201/9780203756881-28

Sahrawat, K.L. and Narteh, L.T. 2006. A fertility index for submerged rice soils. *Communications in Soil Science and Plant Analysis* 33(1-2):229-236, doi:10.1081/CSS-120002389.

Sardiana, I.K., Susila, D., Supadma, A.A. and Saifulloh, M. 2017. Soil fertility evaluation and land management of dryland farming at Tegallalang Sub-District, Gianyar Regency, Bali, Indonesia. *IOP Conference Series: Earth and Environmental Science* 98(1), doi:10.1088/1755-1315/98/1/012043.

Singh, B. and Singh, Y.-S. 2015. Soil fertility: evaluation and management. In: Rattan, R.K., Dwivedi, B.S., Sarkar, A.K., Bhattacharyya, T., Tarafdar, J.C. and Kukal, S.S. (eds.), *Soil Science: An Introduction*, Publisher: Indian Society of Soil Science.

Spaccini, R., Zena, A., Igwe, C.A., Mbagwu, J.S C. and Piccolo, A. 2001. Carbohydrates in water-stable aggregates and particle size fractions of forested and cultivated soils in two contrasting tropical ecosystems. *Biogeochemistry* 53(1):1-22, doi:10.1023/A:1010714919306.

Takele, L., Chimdi, A. and Abebaw, A. 2015. Dynamics of soil fertility as influenced by different land use systems and soil depth in west Showa zone, Gindeberet district, Ethiopia. *Agriculture, Forestry and Fisheries* 3(6):489-494, doi:10.11648/j.aff.20140306.18.

Thomas, G.W. 1983. Exchangeable Cations. In: Page, A.L. (Ed.), *Method of Soil Analysis*. doi:10.1007/978-3-540-31211-6_22.

Tilahun, G. 2007. Soil Fertility Status as Influenced by Different Land Uses in Maybar Areas of South Wello Zone, North Ethiopia. A thesis submitted to the Faculty of the Department of Plant Sciences, School of Graduate Studies, Haramaya University, Ethiopia.

Tucker, B.B. and Kurtz, L.T. 1961. Calcium and magnesium determinations by EDTA titrations. *Soil Science Society of America Journal* 25(1):27-29. doi:10.2136/sssaj1961.03615995002500010016x.

USDA and Committee, C.R. 2000. Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters. In Pierzynski, G.M. (ed.), Southern Cooperative Series Bulletin. North Carolina State University.

Walkley, A.J. and Black, I.A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Science* 37:29-38.

Zádorová, T., Jakšík, O., Kodešová, R. and Penížek, V. 2011. Influence of terrain attributes and soil properties on soil aggregate stability. *Soil and Water Research* 6(3):111-119, doi:10.17221/15/2011-swr.

Zingore, S., Tittonell, P., Corbeels, M., van Wijk, M.T. and Giller, K.E. 2011. Managing soil fertility diversity to enhance resource use efficiencies in smallholder farming systems: A case from Murewa District, Zimbabwe. *Nutrient Cycling in Agroecosystems* 90(1):87-103, doi:10.1007/s10705-010-9414-0.