

Research Article

Soil properties of agricultural area in karst terrain of Parakan, Pangandaran, West Java, Indonesia

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Abstract

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Karst terrain in the mountainous of Pangandaran associates with terra rossa, a clayed soil characterized by reddish in colour, thick solum and neutral acidity. Farmers in Parakan area, Parigi District of Pangandaran, usually cultivate cash crops in terra rossa. Nowadays, farmers have no information about the properties of the soil, which is an important factor to maintain and increase plant productivity. The objective of this descriptive quantitative study was to verify the soil characteristic included physicochemical and microbiological properties in a selected agricultural field of Parakan. The soil samples were taken from three different areas covered with different vegetation. The study showed that terra rossa in the karst area is a non-saline soil with neutral acidity and low electrical conductivity. The texture of all soils were clay contained >50% clay particle. The soils were low in organic carbon, total nitrogen and available phosphor; but high in total phosphor and potassium, as well as cation exchange capacity. The population of soil microbes include total and fungal bacteria, as well as nitrogen-fixing Azotobacter and phosphate solubilizing bacteria, were average. In order to increase the organic carbon level; and the availability of phosphor and nitrogen, organic matter amendment is needed.

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Introduction

Food crops cultivation in karst landscape has been carried out by Parigi farmers for decades. The genesis of karst terrains is dominated by chemical dissolution instead of mechanical processes, commonly with well-developed secondary porosity (Merino and Banerjee, 2008). The karst landform describes a recognizable topography that implies the dissolution of underlying rocks by ground water, surface water or precipitation (Haryono et al. 2017; Veress, 2020). The soluble rocks associated with carbonate rocks include limestone, dolomite, gypsum and rock salt (Veress, 2020). The dissolving product will be sculpted into the karst terrain.

In common, karst areas associate with terra rossa; a clayed soil distinguished by reddish in colour, thick solum and neutral acidity, and developed from volcanic ash associated with karst carbonates (Merino and Banerjee, 2008). Typically, terra rossa is found in the Mediterranean region; In Indonesia, terra rossa is also developed on limestone of Gunung Kidul, Central Java as well as in Pacitan, East Java (Mulyanto et al., 2011). The terra rossa in Parakan area developed in between the foothills of karst mountains. Since the soil depth in the foot, ridge and top of karst hill is too thin for food crops production, the farmers in Parigi cultivate food crops in terra rossa.

Agriculture in Parakan provides food, mainly vegetables and pulses, as well as livelihood for the

community. In 2018, farmers of Parakanmanggu planted lowland rice of 188 ha, upland rice of 25 ha, corn of 30 ha, groundnut of 50 ha, soybean of 50 ha and cassava of 5 ha (BPS, 2019). Diverse banana varieties grow naturally or have been cultivated in a very limited area. In Selasari, the other village of Parigi District, the land use of certain karst is a paddy field that provides staple food reserve for a year (Hindersah et al., 2020).

The land use for agriculture in a marginal environment (such as karst) is protected by legal formal and indigenous law. Karst area is determined by the regulation of the Indonesian Ministry of Energy and Mineral Resources number 17 the year 2012. The regulation is intended to protect the karst terrain include the settlements and agriculture in the area. Based on that regulation, karst landscape is a conservation area that contains some unique components that function to control the water system. Kurniati et al. (2019) have invented some indigenous law to protect water availability in Parigi.

In order to protect agricultural land for food production, the Indonesian Ministry of Agriculture launched regulation no 79 the year 2012 concerning Guidelines for Land Suitability. Unfortunately, farmers in Parakan do not have any information about the physicochemical and biological soil composition; the basic soil properties data is needed for soil suitability determination. The data are useful to determine the need for fertilizer and soil also treatment for increasing soil and plant productivity.

Organic carbon and acidity (pH) of soil can predict soil productivity. Soil organic matter (SOM) supplies nutrients through the enzymatic process and maintain the stability of soil aggregates (Oldfield et al., 2017). Soil reaction affects the availability of nutrients uptake by roots. Neutral soils support the availability of plant nutrients, mainly phosphor (P). In acid soils, the availability of nitrogen (N), phosphor (P), and potassium (K) are reduced, the calcium and magnesium contents in the soil are lower, but the metals are mobilized (Yun and Yu, 2015). The content of major essential nutrients in the soil, i.e. N, P and K, as well as ionic salts, influence plant growth and yield. Moreover, organic matter and the presence of clay

affect the cation exchange capacity that further dictates the soil ability to supply and retain cations.

Soil organic matter and the availability of nutrient are also prominent for the growth and activities of beneficial microbes that regulate the nutrient cycle in soil. Nitrogen-fixing *Azotobacter* and phosphate-solubilizing bacteria (PSB) involve in the increment of N and P availability, respectively (Sivasakthi et al., 2017; Kalayu, 2019). Moreover, the soil quality is also determined by the count of total bacteria and fungi in the soil; both microbes enable to bring back the fertility of degraded land and soil through diverse processes (Rashid et al., 2016).

Despite the good price of groundnut and sweet corn, the productivity of both cash crops in Parakanmanggu were only 1.3 t ha⁻¹ and 8.1 t ha⁻¹, respectively; lower than optimal yield about 2.2 t/ha for groundnut and 14 t ha⁻¹ for sweet corn in Indonesia. Unfortunately, the productivity of other vegetable and pulse in Parakanmanggu is not yet recorded. Appropriate fertilization based on soil properties is suggested elsewhere for yield increment. The first step to increase the soil productivity and hence crops yield by fertilization is to assess the existing soil quality, including physical, chemical, and biological properties. The objectives of this study were to examine the soil physicochemical properties related to plant needs as well as the population of certain microbes, mainly beneficial microbes in a selected agricultural field of Parakan, Pangandaran.

Materials and Methods

The study of soil characteristic was carried out in Parakan area located in Parakanmanggu Village, Parigi District, Pangandaran Regency, West Java, Indonesia (Figure 1) from July 2020 to September 2020. The geographic coordinate of the studied area is about 7.63868° S, 108.46628° E. Regional geological conditions of the study area, according to Simandjuntak and Surono (1992) was limestone member of the Pamutuan Formation (Tmpl) composed of calcarenite and clastic limestone interspersed with claystone marl.

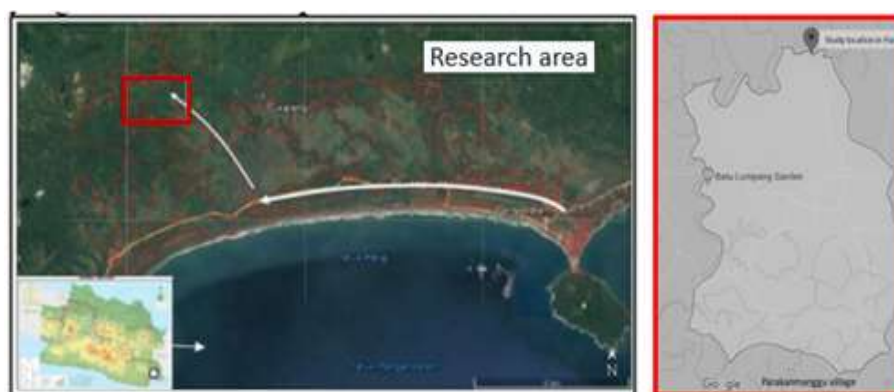


Figure 1. The study area of Parakan area in Parakanmanggu Village of Parigi District (source: google earth).

Stratigraphically, limestone members of the Tmpl are overlapping in line with the Jampang formation, fingers with the tuf napalan formation members guidance. The area is dominated by the mountainous landscape located in the tropics; the altitude of sampling areas was 110-132 m above sea level. The annual temperature, humidity and rainfall of Parigi District are about 25 °C, 85% dan 4,000 mm, respectively.

The research was done by descriptive quantitative methods by elaborating primary data of soil properties in the agricultural area of Parakan, in Parakanmanggu village. Two soil samples were taken up from agricultural fields where the farmers cultivated the most important commodities: groundnut in mixed culture with sweet corn and banana in single culture (Figure 2a and Figure 2b). Other soil samples

were obtained from the field covered by *Albizia falcata* tree (Figure 2c).

Soil sampling was carried out by purposive sampling with a gridline intersection method. The dimension of each sampling area was 10 x 10 m, where four samples of 250-g bulk soil were collected from 20-cm depth by using an auger. All samples were then mixed evenly, put into transparent polyethylene bags and placed in a shady place before transporting to the laboratory.

The bulk soil was then analyzed for physicochemical properties, including acidity (pH), electrical conductivity (EC), nutrients content of nitrogen, phosphorus, potassium, calcium, sodium, and magnesium, H^+ and Al^{3+} ; and texture. Cation exchange capacity (CEC) and base saturation (BS) values were then calculated.



Figure 2. Soil sampling area of groundnut (a), banana (b) and albizia (c) plantation in Parakanmanggu village. Photographs provided by Sondi Kuswaryan.

All physicochemical properties were analyzed by AOAC method (AOAC, 2012), while soil texture was determined by Hydrometer methods (Agus et al., 2006). Other samples of 100-g bulk soil were also collected from the same sampling points for microbial analysis. The samples were put in a cold bag during transport to the laboratory. Enumeration of beneficial microbes was performed by serial dilution plate method using 0.85% of sodium chloride (Sanders, 2012). All soil analysis has been carried out in duplo.

The Azotobacter and PSB were plated in N-free Ashby's mannitol agar and Pikovskaya agar at neutral acidity, respectively (Atekan et al., 2014; Hindersah et al., 2018); while the total bacteria dan fungi were counted by plating in nutrient agar and potato dextrose agar respectively (Davet and Rouxel, 2000; Uthayasooryan et al., 2016). The cultures were incubated in the incubator chamber at 30 °C for 48 hours for bacteria and 72 hours for fungi prior to colony appearance. Each single distinct colonies grown on the plate were counted under a magnifying glass.

Results and Discussion

The texture of soil below all vegetations is clay that dominated by more than 50% of clay particle (Table

1). The composition of sand, silt and clay particle in soils did not vary.

Tabel 1. Particle composition of soil under vegetation in the agricultural area of Parakan in Parigi.

Soil Particle	Vegetation		
	Groundnut	Banana	Albizia
Sand (%)	10.5	7	6.5
Silt (%)	29.5	36.5	29.5
Clay (%)	60	57.5	63

Table 2 shows that all soils were neutral in reaction and low in electrical conductivity (EC). The acidity and EC of soil used for annual crops production were slightly lower than soil under Albizia. In general, soils were low in organic carbon and total nitrogen resulted in very low C/N (Table 3).

Tabel 2. The acidity (pH) and electrical conductivity (EC) of soils in Parakan of Parigi.

Soil Properties	Vegetation		
	Groundnut	Banana	Albizia
pH H ₂ O	6.7	7.0	7.5
pH KCl	4.3	4.5	4.5
EC (dS m ⁻¹)	1.8	1.2	2.3

The total content of P_2O_5 , as well as K_2O , were high in all soil, but the availability of P_2O_5 for plant uptake was limited in all soil samples. The concentration of Na^+ and K^+ was low, Ca^{2+} was average and Mg^{2+} was high resulted in high CEC of all soils. The soils had high base saturation with the soil's cation exchange sites occupied by potassium, calcium and magnesium. The aluminium (Al^{3+}) was only detected in the soil below groundnut plantation. The acidic cations (H^+ and Al^{3+}) were not dominant that is correlated with neutral pH depicted in Table 2.

Table 3. Composition of plant nutrients of soil under vegetations of agricultural field in Parakan of Parigi.

Chemical properties	Vegetation		
	Groundnut	Banana	Albizia
Organik Carbon (%)	0.51	1.00	1.44
Total Nitrogen (%)	0.17	0.25	0.24
C to N ratio	3	4.00	6
P_2O_5 Olsen (mg kg^{-1})	14.45	10.95	5.82
Total P_2O_5 (mg 100 g^{-1})	52.53	55.12	66.24
Total K_2O (mg 100 g^{-1})	39.08	45.00	43.01
Sodium (cmol kg^{-1})	0.17	0.21	0.09
Potassium (cmol kg^{-1})	0.21	0.18	0.17
Calcium (cmol kg^{-1})	8.77	9.11	9.28
Magnesium (cmol kg^{-1})	2.72	2.82	2.88
Al^{+3} (cmol kg^{-1})	0.89	0.00	0
H^+ dd (cmol kg^{-1})	1.17	0.33	0.49
CEC (cmol kg^{-1})	35.86	36.79	39.6
Base saturation (%)	33.10	33.49	31.36

Soil microbial composition and diversity

The population of total bacteria as well as fungi, nitrogen-fixing *Azotobacter* and PSB in bulk soil did not vary (Table 4). The total bacteria, as usual, was relatively abundant compared to total fungi, while the *Azotobacter* population was lower than the PSB count. Based on colony characteristics (Figure 3), the diversity of bacteria (Figure 3a) in all soils was relatively less abundant than the fungi (Figure 3b). We found only 4 types of colonies of bacteria agar plates (Figure 3a), while at least 8 types of colonies were identified from plates of PDA (Figure 3b). *Azotobacter* is characterized by a rounded, convex and transparent colony with smooth boundary (Figure 3c) in Ashby's

mannitol media, while PSB was identified by halo zone around the colonies (Figure 3d).

Table 4. Microbial population in the bulk soil of agricultural land in Parakan, Parigi District.

Microbes	Vegetation		
	Groundnut	Banana	Albizia
Total bacteria (10^8 CFU g^{-1})	37.5	73.0	39.0
Total fungi (10^3 CFU g^{-1})	91.5	50.0	40.5
<i>Azotobacter</i> (10^3 CFU g^{-1})	23.0	39.5	11.0
PSB (10^5 CFU g^{-1})	73.0	67.5	41.0

*PSB, phosphate solubilizing bacteria.

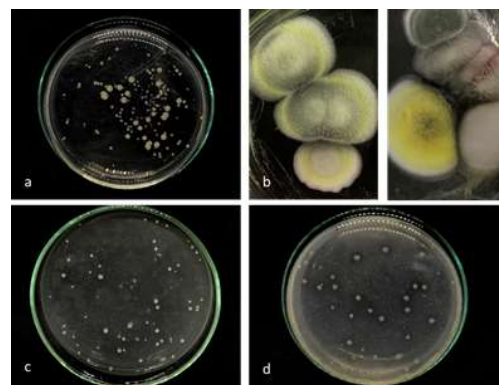


Figure 3. Microbial colonies in plate agar of total bacteria (a), total fungi (b), *Azotobacter* (c) and phosphate solubilizing bacteria (d) isolated from groundnut plantation in Parigi.

Our study is the first one to verify the actual properties of soil not only in Parakanmanggu village but also in Parigi District. Due to the weathering of iron and aluminium during soil genesis, the colour of terra rossa became reddish, reddish-brown or blackish-brown (Hertanto et al., 2011). In this study, the colour of soil in groundnut and albizia plantation were reddish-brown while the soil in banana plantation was blackish-brown.

The texture of soils in the study area was clay with the composition of clay particle $>50\%$. The obstacle of annual crops cultivation in clayed soil is mainly root growth restriction and mechanical compaction resulted in water logging in the rainy season. The farmers overcome this obstacle by intensive soil ploughing and mixing with the limited amount of crops waste with top soil before planting. They rarely incorporate decomposed organic matter due to the limited supply of animal manure and another good quality manure.

The soil pH is about neutral, although the studied areas are located in a carbonate rocks environment.

The neutral soil reaction verified that the soil was in the late development stage resulted in the intensive leaching of calcium (Mulyanto, 2020). Neutral soil reaction will optimize essential nutrients uptake and decrease the mobility of micronutrients. Metal toxicity includes heavy metal cadmium and lead toxicity is only present in the acid soil where the mobility of metal is high (Yun and Yu, 2015).

Most food crops grow better in soil with a pH between 5.5 and 7.5, but some crops need a lower pH (Oshunsanya, 2018). Groundnut in Indonesia grow in soil with a pH between 6-7 and the pH of 5.6 is best for groundnut to grow. Contrary, the best soil pH for sweet corn growth in Indonesia is between 5.5-7.0. The best growth of banana in Indonesia needs organic matter-rich soil but banana can grow in limed soil; the soil pH for banana growth in Indonesia is 4.5-7.5. Electrical conductivity of nutrients reflects the concentration of ionic nutrients in soil solution. This study showed the salinity of all soils was lower than 4 Ds m^{-1} which is characteristic of non-saline soil.

Soil reaction dictates soil microbe's proliferation and activity. In neutral soil, bacterial growth is increased and fungal proliferation is limited. The population of total bacteria and fungi, as well as N-fixer *Azotobacter* and PSB in bulk soil, agree with most mineral soil. In common, the population of both bacteria in soil higher than fungi. The bacterial and fungal counts in this study agree with the bacterial population of about 10^6 CFU g^{-1} and the fungal population of about 10^4 CFU g^{-1} in the soil humus (Jan et al., 2020).

The amounts of organic-C, total N, and available P in soils were low. Moreover, the C/N of soil is too low, resulted in the mobility of nitrogen, and the N source in the soil become limited without continuous fertilization. Low C/N also causes limited SOM degradation, the important enzymatic process for supplying nutrient and maintaining soil physical properties. Organic carbon content reflects the level of SOM that has a significant role in maintaining soil quality. Soil organic matter is important substances for increasing water holding capacity and cation exchange capacity and improving or maintaining soil structure (Oldfield et al., 2017). Organic matters are slow-released plant nutrient source to maintain nutrient supply continuously. Soils contain low total N; lack of sufficient N will possibly cause N deficiency of next crops, especially non-leguminous crops. However, planting groundnut can increase N supply to the plant due to N fixation by rhizobia in root nodules.

Based on the pH, EC and CEC values, the terra rossa in Parakan area is possibly suitable for groundnut, sweet corn, low land vegetable and banana cultivation, although the pH was slightly too high for groundnut. The solum depth of terra rossa is varying from 0.30 cm to 5.4 m (Feng and Zhu, 2009; Feng et al., 2009; Lucke et al., 2014), while the soil depth in the study area was up to 6 m, possibly caused by soil erosion from terra rossa in the higher altitude. Agriculture in soil with deep solum is promising.

However, the farmers need to change nutrient management for sustainable agriculture; they should not only rely on actual soil nutrients. Appropriate inorganic and organic fertilization is a must for increasing long term crops productivity.

In Parakan, maintaining soil pH is an important step to prevent low N, P and K uptake by plants. On the other hand, the content of nitrogen and available P in Parakan soil was low. Application of mineral fertilizer such as urea as a nitrogen source could decrease the soil acidity (Tian and Niu, 2015) due to nitrification (Oshunsanya, 2018). Organic matter amendment mixed with the correct amount of inorganic fertilizer is a better way to prevent soil acidification and, at the same time, increased N, P and K availability. Organic matters have the acid buffering capacity which is related to their functional groups; carboxylic and phenolic groups protonated the H^+ and removed it from the soil solution (Kosobucki and Buszewski, 2014; Xu et al., 2016). Neutral pH also induces nitrogenase of *Azotobacter* to fix N_2 to ammonia and then nitrate that available for root uptake. Moreover, PSB prefers a neutral environment to solubilize unavailable P to the available one.

The importance of regulation for protecting agricultural soil, mainly terra rossa is not only related to the legal aspect of the area. Increased crops production will encourage the farmer to maintain their activity that possibly increases their revenue. Parigi District is directly adjacent to the tourism activity in the coastal area of Pangandaran, and become the buffer zone for maintaining the water source of the tourism area there. The benefit of agriculture in the mountainous area of Parigi will also prevent the Parigi community from earning money in another district as well as preserve the karst terrain. Information about soil properties in agricultural land gives the farmers several ways to increase cash crops productivity.

Conclusion

The properties of terra rossa under different vegetation in the karst environment of Parakan, Parigi District of Pangandaran was not significantly different. All soils contain more than 50% clay; and has neutral pH with low electrical conductivity, which is the characteristics of non-saline soil. The content of organic carbon, total nitrogen and available phosphor was low, but the soils have high total phosphor as well as potassium. The cation exchange capacity of all soils were high, which might be related to the high clay particle in soil. Nonetheless, the population of soil microbes include total and fungal bacteria, as well as nitrogen-fixing *Azotobacter* and phosphate solubilizing bacteria, was average since neutral pH induces the growth of bacteria. The study showed that the organic matter content of all soil was low, then we suggest the farmers incorporate organic matter during soil preparation and carry out the nitrogen fertilization in an appropriate amount.

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References

- Agus, F., Yusrial, and Sutono. 2006. Soil texture determination. In Kurnia, U., Agus, F., Adimihardja A. and Dariah, A. (Eds.), *Soil Physical Properties and Analysis Methods*. Indonesian Agency Agricultural Land Resources Research and Development, Bogor. pp 43-62 (in Indonesian).
- AOAC. 2012. Official Methods of Analysis 19th edition. Association of Official Analytical Chemist, Washington DC, USA, 2012.
- Atekan, A., Nuraini, Y., Handayanto, E. and Syekhfani. 2014. The potential of phosphate solubilizing bacteria isolated from sugarcane wastes for solubilizing phosphate. *Journal of Degraded and Mining Lands Management* 1(4): 175-182, doi: 10.15243/jdmlm.2014.014.175.
- BPS. 2019. *Parigi District in Figures 2018*. Central Bureau of Statistik Ciamis Regency, Ciamis, Indonesia, 36 pages (in Indonesian).
- Davet, P. and Rouxel F. 2000. *Detection and Isolation of Soil Fungi*. Science Publishers, Inc. Enfield, New Hampshire, USA. 188p
- Feng, J-L. and Zhu, L-P. 2009. Origin of terra rossa on Amdo North Mountain on the Tibetan plateau, China: evidence from quartz. *Soil Science and Plant Nutrition* 55(3): 407-420.
- Feng, J-L., Cu, Z-C. and Zhu, L.P. 2009. Origin of terra rossa over dolomite on the Yunnan-Guizhou Plateau, China. *Geochemical Journal* 43: 151-166.
- Haryono, E., Putro, S.T., Surtman and Sutikno. 2017. Polygonal karst morphology of Karangbolong area, Java-Indonesia. *Acta Carsologica* 46(1): 63-72.
- Hertanto, H.B., Ramelan, A.H. and Budiastuti, M.S. 2011. The development of karst area ecotourism object potency in the West Pacitan Regency of East Java Province. *Ekosains* 3(2): 1-30 (in Indonesian).
- Hindersah, R., Handyman, Z., Indriani, F.N., Suryatmana, P. and Nurlaeny, N. 2018. Azotobacter population, soil nitrogen and groundnut growth in mercury-contaminated tailing inoculated with Azotobacter. *Journal of Degraded and Mining Lands Management* 5(3):1269-1274.
- Hindersah, R., Kurniati, N., Sukarsa, D.E. and Kuswaryan S. 2020. Sustainable food crop production in karst area of Parigi, Pangandaran, West Java: a preliminary study. *Journal of Perspectives on Financing and Regional Development* 8(1): 41-50.
- Jan, U., Feiwen, R., Masood, J. and Chun, S.C. 2020. Characterization of soil microorganism from humus and indigenous microorganism amendments. *Mycobiology* 48(5): 392-398.
- Kalayu, G. 2019. Phosphate solubilizing microorganisms: promising approach as biofertilizers. *International Journal of Agronomy*. 2019: Article ID 4917256.
- Kosobucki, P. and Buszewski, B. 2014. Natural organic matter in ecosystems - a review. *Nova Biotechnologica et Chimica* 13(2): 109-129.
- Kurniati, N., Hindersah, R., Sukarsa, D.E. 2019. Legal aspect of green geotourism development of the karst area in Pangandaran: synchronization between the regulation and the living law. *IOP Conference Series: Earth and Environmental Science* 393 (2019) 012066
- Lucke, B., Kemnitz, H., Bäuml, R. and Schmid, M. 2014. Red mediterranean soils in Jordan: new insights in their origin, genesis, and role as environmental archives. *Catena* 112: 4-24.
- Merino, E. and Banerjee, M.A. 2008. Terra rossa genesis, implications for karst, and eolian dust: a geodynamic thread. *The Journal of Geology* 116(1):62-75.
- Mulyanto, D. 2020. Volcanic materials as a main constituent of red soils overlying the carbonate rock of Karangsari, Wonosari. *Jurnal Tanah dan Air (Soil and Water Journal)* 17(2): 45 – 55 (in Indonesian).
- Mulyanto, D., Subroto, P.S. and Lukito, H. 2011. Genesis of soil pedon tanah development on carbonat rock in Wonosari Gunungkidul. *Forum Geografi* 25(2): 100 – 115 (in Indonesian).
- Oldfield, E.E., Wood, S.A. and Bradford, M.A. 2017. Direct effects of soil organic matter on productivity mirror those observed with organic amendments. *Plant and Soil* 423: 363–373, doi: 10.1007/s11104-017-3513-5.
- Oshunsanya, D.O. 2018. Introductory chapter: relevance of soil pH to agriculture. In: *Soil pH for Nutrient Availability and Crop Performance*. IntechOpen, doi: 10.5772/intechopen.82551.
- Rashid, M.I., Mujawar, L.H., Shahzad, T., Almeelbi, T., Ismail, I.M.I. and Oves. M. 2016. Bacteria and fungi can contribute to nutrients bioavailability and aggregate formation in degraded soils. *Microbiological Research* 183: 26-41.
- Sanders, E.R. 2012. Aseptic laboratory techniques: plating methods. *Journal of Visualized Experiment* 63:e3064.
- Simandjuntak, T.O. and Surono. 1992. Geological map of Pangandaran Quadrangle. Geological Research and Development Centre . Bandung (in Indonesian).
- Sivasakthi, S., Saranraj, P. and Sivasakthivelan, P. 2017. Biological nitrogen fixation by Azotobacter sp.—a review. *Indo Asian Journal of Multidiscipline Research* 3: 1274–1284.
- Tian, D. and Niu, S. 2015. A global analysis of soil acidification caused by nitrogen addition. *Environmental Research Letters* 2015 (10): Article ID 024019.
- Uthayasooriyan, M., Pathmanathan, S., Ravimannan, N. and Sathyaruban, S. 2016. Formulation of alternative culture media for bacterial and fungal growth. *Der Pharmacia Lettre* 8 (1):431-436.
- Veress, M. 2020. Karst types and their karstification. *Journal of Earth Science* 31(3): 621–634.
- Xu, R.K., Qafoku, N.P., van Ranst, E., Li, J. . and Jiang, J. 2016. Adsorption properties of subtropical and tropical variable charge soils: Implications from climate change and biochar amendment. *Advance Agronomy* 135: 1–58.
- Yun, S-W. and Yu, C. 2015. Immobilization of Cd, Zn, and Pb from Soil treated by limestone with variation of pH using a column test. *Journal of Chemistry* 2015: Article ID 641415.