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Research Article
Cover Crop Residue Effects on Soil and Corn Performance in Ex-Nickel Mining Soils

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Abstract

Background and Objective: The use of cover crop residue for improving soil quality has been widely applied. Nevertheless, the effectiveness for improving ex-mining soil quality and crop performance at ex-mining soils is rarely documented. This study investigated the effect of cover crop residue on soil quality enhancement and corn production established in ex-nickel mining soils. **Materials and Methods:** An experiment comprising three treatment of cover crops residue, including *Eleusine indica, Centrosema pubescens* and *Calopogonium mucunoides*, arranged in a completely randomized design with three replications. The soil improvement process was evaluated by several parameters, such as soil acidity, soil organic carbon, total nitrogen, exchangeable potassium, exchangeable magnesium and heavy metals. On the other side, corn's growth performance was assessed using some attributes, i.e. height, diameter, total leaves, leaf area and biomass accumulation. **Results:** The results demonstrated that the cover crops residue had the potential to improve ex-nickel mining soil quality. The highest soil improvement was recorded in total nitrogen (700-800%). The treatments also showed a positive advantage to reduce heavy metals content, particularly for Fe, Mn and Zn by approximately 51.58-85.74%. No significant difference in corn growth performance was found in this study ($p>0.05$). However, the utilization of crop residue from *Calopogonium mucunoides* exhibited relatively higher total biomass than other treatments by around 3.08 ± 1.99 g plant^{-1}. **Conclusion:** Despite the treatments had no significant effect on corn performance. This study realized that cover crop residue could improve soil conditions for providing better environmental conditions for agriculture development.

Key words: Agriculture development, ex-nickel mining, heavy metals, soil enhancement, total nitrogen, soil microorganisms, phytoremediation, topography

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Integration of mining reclamation and food security currently become the most crucial issue in tropical land management[1], including in Indonesia. In this context, the implementation of mining reclamation is expected to accelerate the land cover process by conducting revegetation and providing additional benefits for rural development and poverty alleviation[2]. This objective can be realized by converting the ex-mining area to agricultural land. However, the scenario is not easy to conduct since the soil characteristics at the ex-mining area have low fertility and high soil acidity due to contamination[3-5]. Moreover, the soil quality at the ex-mining area also has an excessive amount of heavy metals[6-8]. This condition is not suitable for supporting crop cultivation because many soil parameters become the limiting factors for plant growth and development. To anticipate the problem, soil amendment strategies can enhance soil quality at the ex-mining area, one of them is using cover crop residue[9].

Several previous studies report that the use of cover crop residue for improving soil quality at the ex-mining site has been intensively conducted in many regions[10-12], primarily at the location of ex-coal mining. The use of cover crop residue for mining reclamation provides benefits in improving soil structure, increasing soil organic matter, maintaining soil moisture and accelerating the activity of soil microorganisms[10,13]. In addition, the utilization of this treatment for phytoremediation in ex-mining soil highly increases the phosphorus availability by around 40-50%[14]. Those explanations confirm the potential use of cover crop residue as one of the methods for soil amendment at the ex-mining area. However, cover crop residue as a soil amendment treatment at the ex-mining area has to examine in other locations since every type of mining result in different problems of soil contamination. Furthermore, the occurrence of site interaction among soil, climate and topography may also affect the effectiveness of cover crop residue for improving soil quality at the ex-mining location[15].

Moreover, the soil type in this area is predominantly ultramafic soil that naturally has low fertility due to high heavy metals content[16]. In this case, the application of cover crop residue is also directed to anticipate this challenge. It's a hypothesis that covers crop residue provides a meaningful role in improving soil quality and the growth performance of corn at the ex-nickel mining soils.

This study aims to evaluate the effect of cover crop residue on soil improvement and corn performance at the ex-nickel mining soils located in Southeast Sulawesi. The research is important to implement because many ex-nickel mining lands still required reclamation activity in this location.

MATERIAL AND METHODS

Study area: This study was conducted at the laboratory level for facilitating the measurement process periodically. The study site was located at the field nursery managed by the Department of Soil Science, Faculty of Agriculture, Halu Oleo University from September, 2018-July, 2019. Topography was relatively flat with a slope level of 0-8%. Altitude reached 55 m above sea level, with a mean daily temperature was 27.68°C with a minimum of 23.87°C and a maximum of 32.05°C. Annual rainfall varied from 1,600-2,500 mm year^{-1} during the last five years from 2016-2020. The highest rainfall occurred in January. Dry periods were relatively more extended than five months from May-September. The average air humidity was 80.9%, with a minimum of 73% and a maximum of 86%.

Experimental design: An experiment comprising three treatments of cover crop residue was set up using a Completely Randomized Design (CRD) with three replications for every treatment. The source of cover crop residue was from three different species that commonly used in plantations, namely *Eleusine indica*, *Centrosema pubescens* and *Calopogonium mucunoides*. Two species were categorized as family Leguminosae (*C. pubescens* and *C. mucunoides*), while another species was classified into family Gramineae (*E. indica*).

The soil materials used in this research were taken from the ex-nickel mining areas located in Konawe District. Soil properties were quantified first to evaluate its characteristics before starting the application of treatments (Table 1). This step was importantly conducted to obtain the preliminary information about soil characteristics as basic data to assess the effectiveness of treatment application for soil improvement. After obtaining the initial soil data, site

Table 1: Characteristics of soil materials from ex-nickel mining area used in this study

Parameters	Symbol	Unit	Value
Actual soil acidity	pH	-	5.64
Soil organic carbon	SOC	g kg^{-1}	0.07
Total nitrogen	TN	g kg^{-1}	0.03
Exchangeable potassium	Exc-K	mg kg^{-1}	0.22
Exchangeable magnesium	Exc-Mg	mg kg^{-1}	0.04
Iron	Fe	mg kg^{-1}	7.44
Manganese	Mn	mg kg^{-1}	7.44
Zinc	Zn	mg kg^{-1}	2.68

Data were presented in pH: Actual soil acidity, SOC: Soil organic carbon, TN: Total nitrogen, Exc-K: Exchangeable potassium, Exc-Mg: Exchangeable magnesium, Fe: Iron, Mn: Manganese and Zn: Zinc preparation was implemented to create a homogeneous condition in the experiment. This effort was exceptionally required to minimize the bias observations due to the influence of environmental conditions outside the treatment[17].

Afterwards, the soil material was placed in the bucket and provided a name tag to guarantee the specific code for every treatment. Then, the cover crop residue was mixed into the bucket with a dose of 200 g for each treatment. A month later, the corn seed was planted in the bucket. Corn was selected as an alternative crop species since this plant was highly sensitive to soil fertility. In this study, the number of plants in every plot was only one to derive more accurate observations at the individual plant level. The additional fertilizer was not given to observe the natural influence of cover crop residue on soil improvement and the growth performance of corn. However, the maintenance activities such as weed control and the watering process were still conducted to support the early growth of corn.

Data collection: Data were collected gradually in a chronological manner. Soil characteristics were measured two times, i.e. before treatment application and after corn harvesting. Several parameters were selected to quantify the soil properties, including soil acidity, soil organic carbon, total nitrogen, exchangeable potassium, exchangeable magnesium and heavy metals content (iron, manganese and zinc). Soil acidity was determined by a digital pH meter while soil organic carbon was quantified using Walkley and Black method[18]. Total nitrogen was calculated using the Kjeldahl method[19] while exchangeable potassium was estimated using a spectrophotometer (Hitachi Double Beam U-2900, Kendari, SE Sulawesi, Indonesia). The exchangeable magnesium and heavy metals were quantified using atomic absorption spectrophotometry (Hitachi Z-2000 Tandem Type Atomic Spectrophotometry, Kendari, SE Sulawesi, Indonesia). The protocol of soil analysis was processed following the guidance of soil and water analysis[20].

The growth performance of corn was measured periodically every two weeks. The harvesting period of corn was conducted in the sixth week. Our study focused on the growth performance of corn at the final observations because it represented the adaptability of corn toward the soil improvement process due to the effect of cover crop residue. Some parameters were measured in this period, such as height, diameter, total leaves, leaf area and biomass distribution. The measurement of plant biomass was conducted in every corn component, namely root, shoot and flower.

Data analysis: A descriptive test was applied to identify the range of data distribution[21]. The normality of data was examined using the Shapiro-Wilk test[22]. The homogeneity of variance among treatments was evaluated by the Fligner-Killeen test[23]. The comparison of soil improvement among treatments was presented descriptively by the actual value and percentage unit of improvement in every parameter. Meanwhile, the growth performance of corn among treatments was analyzed by the Kruskal-Wallis test and followed by the Kruskal-Nemenyi test[24]. There was a relationship between soil improvement and the growth performance of corn, the correlation analysis was applied using the Pearson method with a pallet matrix[25]. The process of data analysis was conducted using R software version 4.0.2. with a significant level of 5%.

RESULTS AND DISCUSSION

Soil improvement: Summarized results of the observation demonstrated that the application of cover crop residue showed a positive role in improving soil quality from the ex-nickel mining soils (Table 2). The use of cover crop residue from all treatments had a potential contribution to reducing soil acidity and increasing soil organic carbon, total nitrogen, exchangeable potassium as well as exchangeable potassium. Moreover, this study observed that the utilization of cover crop residue as organic matters substantially declined the heavy metal content in the ex-nickel mining soils by approximately 50-80%, particularly for iron, manganese and zinc. Interestingly, our study recorded the highest soil quality improvement among eight parameters found in total nitrogen with a range of 700-800% (Table 2). On another side, the lowest enhancement of soil quality was discovered in soil acidity. According to the results, it was indicated that cover crop residue from family Leguminosae (*C. pubescens* and *C. mucunoides*) improved total nitrogen better than family Gramineae (*E. indica*). In contrast, the use of cover crop residue from family Gramineae resulted in a more significant decline of heavy metal content than Leguminosae, primarily related to iron and zinc. However, every treatment demonstrated a future result to facilitate the soil improvement process at the ex-nickel mining soils.

The cover crop residue was classified as an organic matter that contained an amount of nutrients[26]. The accumulation of nutrients in the organic matter would be released into the soil when the decomposition process occurred[27]. It confirmed why the utilization of cover crop residue had a potential contribution to reducing soil acidity and improving macro nutrients in

Table 2: Details soil improvement for every parameter in three different treatments of cover crop residue

Parameter	Symbol	Unit	*E. indica* Actual value	*E. indica* Percentage improve (%)	*C. pubescens* Actual value	*C. pubescens* Percentage improve (%)	*C. mucunoides* Actual value	*C. mucunoides* Percentage improve (%)
Actual soil acidity	pH	-	6.82	20.92	6.97	23.58	6.68	18.43
Soil organic carbon	SOC	g kg^{-1}	0.36	414.28	0.36	414.28	0.40	471.42
Total nitrogen	TN	g kg^{-1}	0.24	700	0.27	800	0.27	800
Exchangeable potassium	Exc-K	mg kg^{-1}	0.86	290.90	0.74	236.36	0.60	172.72
Exchangeable magnesium	Exc-Mg	mg kg^{-1}	0.14	250	0.16	300	0.14	250
Iron	Fe	mg kg^{-1}	3.07	(58.71)	3.60	(51.58)	3.41	(54.13)
Manganese	Mn	mg kg^{-1}	1.26	(83.05)	1.12	(84.93)	1.06	(85.74)
Zinc	Zn	mg kg^{-1}	0.90	(66.35)	1.05	(60.74)	1.00	(62.61)

Data were presented in the actual value and percentage unit

Table 3: Growth performance of corn at the treatment of cover crop residue

Parameter	Unit	Treatment *E. indica*	*C. pubescens*	*C. mucunoides*	p-value
Height	cm	74.30±3.75[a]	78.26±2.54[a]	78.20±21.06[a]	0.429
Diameter	cm	2.33±0.25[a]	2.37±0.23[a]	2.53±0.06[a]	0.470
Total leaves	-	6.00±0.00[a]	6.00±0.58[a]	6.00±0.58[a]	0.564
Leaf area	cm^2	699.07±84.55[a]	675.49±82.29[a]	583.97±46.74[a]	0.193
Root biomass	g	0.80±0.04[a]	0.74±0.21[a]	0.65±0.30[a]	0.874
Shoot biomass	g	1.89±0.27[a]	2.07±1.26[a]	2.31±1.81[a]	0.956
Flower biomass	g	0.11±0.03[a]	0.14±0.03[a]	0.11±0.02[a]	0.415
Total biomass	g	2.81±0.34[a]	2.95±1.40[a]	3.08±1.99[a]	0.956

Data were demonstrated in mean ± standard deviation. The similar letter in the row indicated there was not a significant difference based on the Kruskal-nemenyi test

Table 4: Comparison of the growth performance of corn between the crop residue from family Gramineae and Leguminosae

Parameter	Unit	Gramineae	Leguminosae
Height	cm	74.30	78.23
Diameter	cm	2.33	2.45
Total leaves	-	6.00	6.33
Leaf area	cm^2	699.07	629.74
Root biomass	g	0.80	0.70
Shoot biomass	g	1.90	2.19
Flower biomass	g	0.11	0.13
Total biomass	g	2.81	3.02

the ex-nickel mining soils. Cover crop residue could also decrease the heavy metals content because it formed complex compounds and made the heavy metals immobile[28]. In the case of mining reclamation, particularly for ex-nickel mining soils, the decreasing soil acidity and heavy metals content became the primary challenge in the process of revegetation. These parameters were the limiting factors that influenced plant survival[29]. Thus, the effort of site preparation was exceptionally required to accelerate the soil improvement process before planting activities. Referring to the results, the application of cover crop residue as the organic matter could become one of the alternative strategies for site preparation in the activity of mining reclamations.

Growth performance of corn: The use of cover crop residue did not provide a significant influence on the growth performance of corn for all observation parameters ($p>0.05$) (Table 3). Nevertheless, this study noted that the utilization of cover crop residue from family Leguminosae demonstrated a higher average corn performance than cover crop residue from the family Gramineae, except in leaf area and root biomass (Table 4). The data of Table 4 show that treatment using cover crop residue from family Leguminosae, the plant height reached 78.23 cm, stem diameter reached 2.45 cm, total leaves reached 6.33 pieces, shoot biomass reached 2.19 g, flower biomass reached 0.13 g and total biomass reached 3.02 g. While the treatment using cover crop residue the family Gramineae, the plant height only 74.30 cm, stem diameter only 2.33 cm, total leaves only 6.00 pieces, shoot biomass only 1.90 g, flower biomass only 0.11 g and total biomass only 2.81 g. Among the treatment applications, the highest average biomass of corn was recorded in the treatment of cover crop residue from *C. mucunoides* (3.08±1.99 g) and followed by *C. pubescens* (2.95±1.40 g) and *E. indica* (2.81±0.34 g) (Table 3). It usually occurred because the accumulation of soil organic carbon and total nitrogen at the treatment of *C. mucunoides* was relatively higher than other treatments (Table 2). This

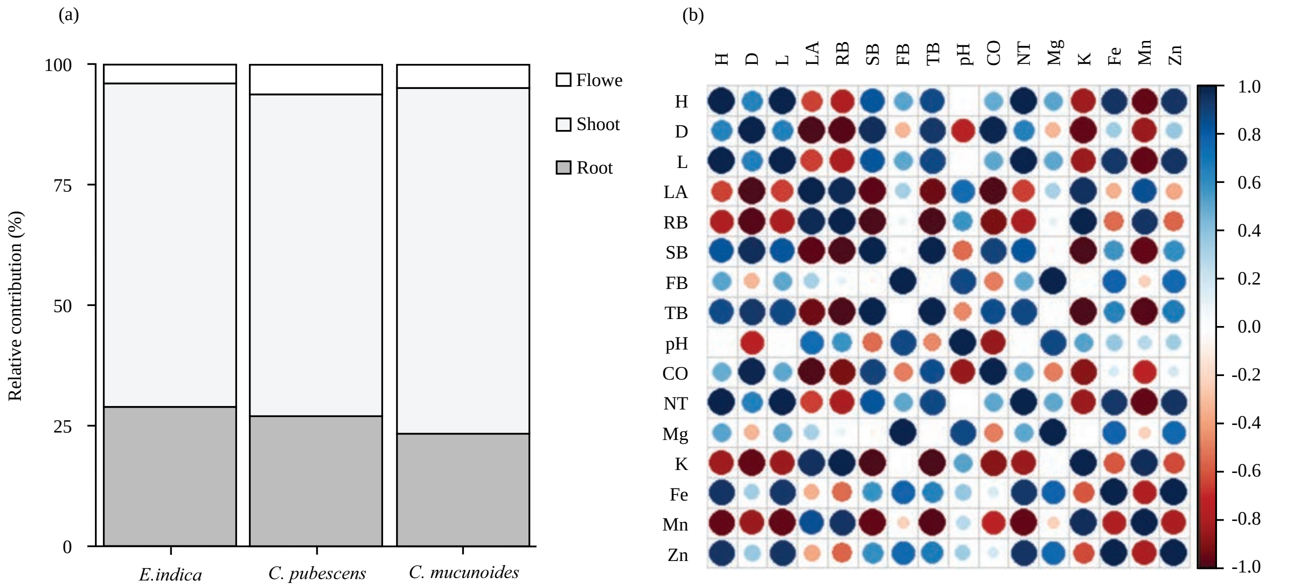

Fig. 1(a-b): (a) Relative contribution to the total biomass and (b) Correlation analysis among soil characteristics and the growth performance of corn

H: Plant height, D: Plant diameter, L: Leaf number, LA: Leaf area, RB: Root biomass, SB: Shoot biomass, FB: Flower biomass, TB: Total biomass, pH: Actual soil acidity, CO: Soil organic carbon, NT: Total nitrogen, Mg: Exchangeable magnesium, K: Exchangeable potassium, Fe: Iron, Mn: Manganese, Zn: Zinc

finding was also confirmed by the results of correlation analysis wherein there was a strong correlation between soil organic carbon and total nitrogen with a total biomass of corn Fig. 1(a-b). The previous studies also supported it wherein the higher availability of soil organic carbon and total nitrogen significantly increased the biomass production of plant[30-32].

The data of Fig. 1(a-b) show that the relative contribution of root biomass to the total biomass at the treatment of *E. indica* was relatively greater than other treatments. This trend could occur since the improvement of exchangeable potassium in this treatment was substantially higher than in other treatments. As one of the macronutrients, potassium availability played an essential role in plant physiology[33], mainly related to the translocation process between source and sink[34]. In the marginal soils, the higher potassium availability could stimulate the more effective root development process[35].A study reported that in facing stress conditions due to the impact of environments, mainly from heavy metals, potassium availability could support plant adaptability[36].

The activity of soil management became the principal challenge in the context of mining reclamation, particularly at the ex-nickel mining soils. Besides having a serious problem related to soil contamination, mining reclamation had to face low soil fertility due to the high soil acidity and deficient nutrients availability. Consequently, the process of revegetation in the ex-mining area required expensive cost and long-time consuming. Therefore, most mining companies seek the most efficient method to accelerate the revegetation in the ex-mining area.

This study has evidenced the potential use of cover crop residue to accelerate the soil improvement at the ex-nickel mining soils. Besides improving nutrient availability, this method could also reduce soil acidity and heavy metals content. Most importantly, the use of cover crop residue had a more affordable cost than other soil amendment strategies. The results of the soil improvement process could be observed at a relatively short period, around 2-3 months. This method could become an alternative strategy for supporting the mining reclamation, primarily at the ex-nickel mining areas in Southeast Sulawesi.

CONCLUSION

This study concluded that the use of cover crop residue had a high potential contribution to improving the soil quality at ex-nickel mining soils in Southeast Sulawesi. The application of treatments provided a substantial role in recovering soil acidity, soil organic carbon, total nitrogen and exchangeable base as well as reducing heavy metals content. Thus, the treatments also gave good advantages for stabilizing better environmental conditions in the context of agriculture development, mainly related to crop cultivation. However, our study did not find a significant effect of cover crop residue on the growth performance of corn. Nevertheless, the application of cover crop residue from *Calopogonium mucunoides* exhibited relatively higher corn biomass than other treatments.

SIGNIFICANCE STATEMENT

This study discovers the use of land cover crop residues that have a high potential to restore ex-mining soil conditions to provide better environmental conditions for agricultural development. This study will help the researcher uncover the critical areas of rehabilitation of post-mining land using land cover residue for agricultural uses, which many researchers could not explore. Our finding revealed that the land cover crop residue has potential for land restoration, especially in post-mining land rehabilitation through adaptive cover crops. Finding adaptive cover crop types is an essential step in the ex-mining land rehabilitation strategy.

REFERENCES

1. Sukarman, S. and R.A. Gani, 2020. Ex-coal mine lands and their land suitability for agricultural commodities in South Kalimantan. J. Degraded Min. Lands Manage., 7: 2171-2183.
2. Wang, J., F. Zhao, J. Yang and X. Li, 2017. Mining site reclamation planning based on land suitability analysis and ecosystem services evaluation: A case study in Liaoning province, China. Sustainability, Vol. 9. 10.3390/su9060890.
3. Buta, M., G. Blaga, L. Paulette, I. Păcurar and S. Rosca *et al*., 2019. Soil reclamation of abandoned mine lands by revegetation in Northwestern part of Transylvania: A 40-year retrospective study. Sustainability, Vol. 11. 10.3390/su11123393.
4. Sukarman, R.A. Gani and Asmarhansyah, 2020. Tin mining process and its effects on soils in Bangka Belitung Islands Province, Indonesia. SAINS TANAH J. Soil Sci. Agroclimatol., 17: 180-189
5. Hindersah, R., Z. Handyman, F.N. Indriani, P. Suryatmana and N. Nurlaeny, 2018. *Azotobacter* population, soil nitrogen and groundnut growth in mercury-contaminated tailing inoculated with *Azotobacter* J. Degraded Min. Lands Manag., 5: 2502-2458.
6. Fashola, M.O., V.M. Ngole-Jeme and O.O. Babalola, 2016. Heavy metal pollution from gold mines: Environmental effects and bacterial strategiesfor resistance. Int. J. Environ. Res. Publ. health, 13: 1-20.
7. Sopialena, S., R. Rosfiansyah and S. Sila, 2017. The benefit of top soil and fertilizer mixture to improve the ex-coal mining land. Nusantara Biosci., 9: 36-43.
8. Štofejová, L., J. Fazekaš and D. Fazekašová, 2021. Analysis of heavy metal content in soil and plants in the dumping ground of magnesite mining factory Jelšava-Lubeník (Slovakia). Sustainability, Vol. 13. 10.3390/su13084508.
9. Leomo, S., M. Tufaila, R. Adawiyah, A.A. Anas and T.C. Rakian *et al*., 2021. Reclamation of ex-nickel mining soil using organic plus fertilizer to support corn cultivation in Southeast Sulawesi. IOP Conf. Ser.: Earth Environ. Sci., Vol. 681. 10.1088/1755-1315/681/1/012034.
10. Pauletto, E.A., L. Stumpf, L.F.S. Pinto, T.S. da Silva and J.V. Ambus *et al*., 2016. Reclamation of a degraded coal-mining area with perennial cover crops.Rev. Bras. Ciênc. Solo, Vol. 40. 10.1590/18069657rbcs20150482.
11. Larney, F.J. and D.A. Angers, 2012. The role of organic amendments in soil reclamation: A review. Can. J. Soil Sci., 92: 19-38.
12. Ghimire, B., R. Ghimire, D. VanLeeuwen and A. Mesbah, 2017. Cover crop residue amount and quality effects on soil organic carbon mineralization. Sustainability, Vol. 9. 10.3390/su9122316.
13. Sayara, T., R. Basheer-Salimia, F. Hawamde and A. Sánchez, 2020. Recycling of organic wastes through composting: Process performance and compost application in agriculture. Agronomy, Vol. 10. 10.3390/agronomy10111838.
14. Leomo, S., M. Tufaila, R. Adawiyah, T.C. Rakian and Muhidin *et al*., 2019. The effectiveness of cover crop and Rhizobacteria as amelioration on ex-nickel mine soil Southeast Sulawesi. IOP Conf. Ser.: Earth Environ. Sci., Vol. 260. 10.1088/1755-1315/260/1/012146.
15. Baumhardt, R.L., B.A. Stewart and U.M. Sainju, 2015. North American soil degradation: Processes, practices and mitigating strategies. Sustainability, 7: 2936-2960.
16. Alam, S., B.H. Purwanto, E. Hanudin and E.T.S. Putra, 2020. Soil diversity influences on oil palm productivity in Ultramafic ecosystems, Southeast Sulawesi, Indonesia. Biodiversitas J. Biol. Divers., 21: 5521-5530.
17. Wirabuana, P.Y.A.P., R. Sadono, S. Juniarso and F. Idris, 2020. Interaction of fertilization and weed control influences on growth, biomass and carbon in eucalyptus hybrid (*E. pellita* × *E. brassiana*). J. Manajemen Hutan Tropika, 26: 144-154.
18. Walkley, A. and I.A. Black, 1934. An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci., 37: 29-38.
19. Adams, C.I. and G.H. Spaulding, 1955. Determination of organic nitrogen by kjeldahl method without distillation. Anal. Chem., 27: 1003-1004.

20. Pansu, M. and J. Gautheyro, 2007. Handbook of Soil Analysis: Mineralogical Organic and Inorganic Methods. Springer, Cham, Switzerland.
21. Mishra, P., C.M. Pandey, U. Singh, A. Gupta, C. Sahu and A. Keshri, 2019. Descriptive statistics and normality tests for statistical data. Ann. Cardiac Anaesth., 22: 67-72.
22. Ghasemi, A. and S. Zahediasl, 2012. Normality tests for statistical analysis: A guide for non-statisticians. Int. J. Endocrinol. Metab., 10: 486-489.
23. Conover, W.J., M.E. Johnson and M.M. Johnson, 1981. A comparative study of tests for homogeneity of variances, with applications to the outer continental shelf bidding data. Technometrics, 23: 351-361.
24. Vargha, A. and H.D. Delaney, 1998. The kruskal-wallis test and stochastic homogeneity. J. Educ. Behav. Stat., 23: 170-192.
25. Charan, G., V.K. Bharti, S.E. Jadhav, S. Kumar and S. Acharya *et al*., 2013. Altitudinal variations in soil physico-chemical properties at cold desert high altitude. J. Soil Sci. Plant Nutr., 13: 267-277.
26. Abdalla, M., A. Hastings, K. Cheng, Q. Yue and D. Chadwick *et al*., 2019. A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. Global Change Biol., 25: 2530-2543.
27. Purwanto, B.H. and S. Alam, 2020. Impact of intensive agricultural management on carbon and nitrogen dynamics in the humid tropics. Soil Sci. Plant Nutr., 66: 50-59.
28. Egli, M., G. Sartori, A. Mirabella, D. Giaccai and F. Favilli *et al*., 2010. The influence of weathering and organic matter on heavy metals lability in silicatic, alpine soils. Sci. Total Environ., 408: 931-946.
29. Yang, S.X., B. Liao, J.T. Li, T. Guo and W.S. Shu, 2010. Acidification, heavy metal mobility and nutrient accumulation in the soil-plant system of a revegetated acid mine wasteland. Chemosphere, 80: 852-859.
30. Wijanarko, A. and B.H. Purwanto, 2017. Effect of land use and organic matter on nitrogen and carbon labile fractions in a typic hapludult. J. Degraded Min. Lands Manage., 4: 837-843.
31. Olowoboko, T.B., J.O. Azeez, O.O. Olujimi and O.A. Babalola, 2018. Availability and dynamics of organic carbon and nitrogen indices in some soils amended with animal manures and ashes. Int. J. Recycl. Org. Waste Agric., 7: 287-304.
32. Xue, Z. and S. An, 2018. Changes in soil organic carbon and total nitrogen at a small watershed scale as the result of land use conversion on the Loess Plateau. Sustainability, Vol. 10. 10.3390/su10124757.
33. Tantriani, T. Shinano, W. Cheng, K. Saito, A. Oikawa, B.H. Purwanto and K. Tawaraya, 2020. Metabolomic analysis of night-released soybean root exudates under high- and low-K conditions. Plant Soil, 456: 259-276.
34. Tränkner, M., E. Tavakol and B. Jákli, 2018. Functioning of potassium and magnesium in photosynthesis, photosynthate translocation and photoprotection. Physiologia Plant., 163: 414-431.
35. Hafsi, C., A. Debez and C. Abdelly, 2014. Potassium deficiency in plants: Effects and signaling cascades. Acta Physiol. Plant., 36: 1055-1070.
36. Sustr, M., A. Soukup and E. Tylova, 2019. Potassium in root growth and development. Plants, Vol. 8. 10.3390/plants8100435.