IOP Conference Series: Earth and Environmental Science

Ameliorant engineering to elevate soil pH, growth, and productivity of paddy on peat and tidal land

IOP Conf. Series: Earth and Environmental Science **648** (2021) 012183 doi:10.1088/1755-1315/648/1/012183

Ameliorant engineering to elevate soil pH, growth, and productivity of paddy on peat and tidal land

R A Saputra and N N Sari

Department of Agroecotechnology, Faculty of Agriculture, Lambung Mangkurat University, Banjarbaru, Indonesia

E-mail: nukhak.sari@ulm.ac.id

Abstract. To support the government's program towards world food barns in 2045, the use of sub-optimal wetlands such as peatlands and tidal land is a viable alternative. The problem of acidity in both types of land can be controlled, one of which is by providing ameliorant. Thus, the purposes of this study were to examine the effect of ameliorant application in increasing soil pH, as well as its influence in increasing the growth and production of paddy plants. The study was conducted using a nested factorial completely randomized design. The factors were soil (peat soil/l1 and tidal swampland/l2) and ameliorant types (without ameliorant/p0, dolomite/p1, chicken manure/p2, paddy husk ash/p3, paddy husk charcoal/p4, and baglog oyster mushroom waste/p5) that given 10 t ha^{-1} each. The results showed that all ameliorants applied could increase soil pH, growth, and paddy yield. Dolomite, chicken manure, and baglog oyster mushroom waste significantly elevated the pH of peat and tidal soils. The highest paddy productivity was at chicken manure application. The application of ameliorant increased soil pH to be suitable pH for paddy growing on peat and tidal soils.

1. Introduction

The government's vision to become a world food barn by 2045 needs an integrated support system. It must be supported by increased agricultural production through intensification and extensification. Intensification by using the high quality of seed, water management, balanced fertilization, integrated pest and disease management, and mechanization to increase cropping index. While extensification by creating the new paddy field area, intercropping with a perennial plant such as palm oil or rubber. However, those are constrained by high land conversion from agricultural land to non-agriculture. The data from the Ministry of Agrarian Affairs and the National Land Agency shows that paddy fields had decreased significantly from 7,750,999 ha in 2013 to 7,105,145 ha in 2018. It means there has been a decrease in the area of paddy fields by around 646 thousand ha or 8% in the last five years. Therefore, optimizing the sub-optimal land use is a viable alternative. South Kalimantan is one of the provinces with quite extensive sub-optimal land. Sub-optimal land in South Kalimantan that can have managed as agricultural land includes peat and tidal land. The land includes irrigated, rainfed, tidal, and lowland swamps cover 55,752; 197,173; 201,979; and 187,673 ha, respectively [1]. The use of adaptive varieties, water management technology, and fertilization are some of the things that have developed and proven to be able to improve the quality and increase the productivity of tidal land [2].

One of the obstacles in the use of peatlands and tides for agriculture is the chemical properties of the soil that are not suitable. The soil reaction (pH) of peat and tidal lands is classified as very acidic to acidic [3]. The status of wetland fertility, in this case, is soil pH, which needs to have increased first to support the growth and development of paddy plants. One of the ways to increase the fertility status of peat and tidal lands is ameliorant application. Amelioration is a practice for improving soils by the addition of so-called soil amendments. These can include fertilizers to overcome mineral nutrient deficiencies. Its additives and chemical substances (naturally or synthetically) that modify soil quality to improve plant health [4]. Organic ameliorant materials include manure, compost, straw, and biochar. Meanwhile inorganic ameliorant includes lime or dolomite, zeolite, and volcanic ash [5].

Among the ameliorants, lime and chicken manure are effective ameliorants to improve acid soil conditions. According to Ar-Riza and Alkasuma [6] reported that lime has a better effect than husk ash and wood ash in neutralizing or reducing levels of toxic ions such as H^+, Al^{3+}, and SO_4^{2-}, increasing the availability of macronutrients P, K, Ca, and Mg, as well as micronutrients Cu and Zn. While chicken manure has a better effect than other organic materials in improving the quality of acid soil. Sufardi et al. [7] reported that ameliorant was able to increase the number of productive tillers and leaf area of paddy in paddy fields. Jamilah and Safridar [8] also reported that ameliorant substances significantly affect the growth and yield of paddy plants. Septiyana et al. [9] studied that ameliorant was able to increase soil pH, it also increases several nutrients needed by paddy plants, which in turn will increase the growth and production of paddy in tidal, peat, and rainfed lowland.

Information regarding the application of ameliorants to soil reaction (pH), growth, and production of paddy grown on sub-optimal land is still limited. Therefore, this study was conducted to examine the effect of ameliorant application on increasing soil reaction (pH) in peat and tidal soils, and the effect on increasing paddy growth and production in peat and tidal soils.

2. Materials and methods

This research was conducted from October to December 2018, at the Greenhouse of the Agroecotechnology Department and the Laboratory of the Soil Department, Faculty of Agriculture, Lambung Mangkurat University, Banjarbaru, South Kalimantan. The study was conducted using a nested factorial completely randomized design with 4 replications. The first factor was the type of soil, which consists of two levels, peat soil (l1) and tidal land (l2). The tidal soil used is type B [10]. The second factor was ameliorant types which consist of without ameliorant (p0), dolomite (p1), chicken manure (p2), paddy husk ash (p3), paddy husk charcoal (p4), and baglog oyster mushroom waste (p5) that given 10 ton ha^{-1} each.

The soil was taken at a depth of 0-30 cm from the soil surface at two different locations, namely peat soil from the Karang Anyar Banjarbaru agricultural land (3.4270 S and 114.7653 E) and tidal marshland from Sungai Rangas Village, Banjar Regency (3.3493 S and 114.7677 E). Stones, gravels, and plant debris were removed from the soil. Then it weighs 10 kg and put it in each pot, ameliorant was added according to the treatment, except for the control. Then, water was added at 3 cm height from the soil surface, then incubated for two weeks. During the incubation period, the water level was maintained at 3 cm above the soil surface to keep soil conditions such as conditions in the field.

The paddy variety used in this study was Ciherang. Seeds were cleaned and sown in trays for 30 days. Then, three plants were transplanted in each pot. Urea, TSP, and KCl fertilizers were applied at a different level of dosage and time. The dose of urea fertilizer was 200 kg/ha, which applied 25% at transplanting as basal fertilizer, 25% at three weeks after planting (WAP), and 50% at 5 WAP. The dose of TSP and KCl fertilizers was 100 kg ha^{-1} applied at the beginning of planting [2].

Data were analyzed by using GenStat 12th edition to understand the effect of ameliorant on changes in soil pH, growth, and paddy yield. The homogeneity test was carried out before the analysis of variance. If the analysis of variance shows a significant different treatment, test was continued using the Duncan's Multiple Range Test at the α 5% level [11].

3. Results and discussion

3.1. Soil Characteristics

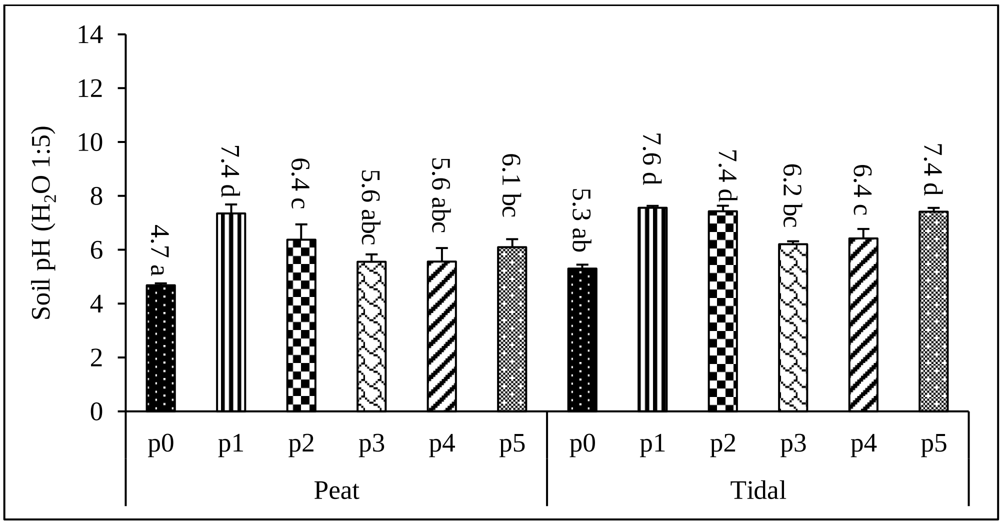
Peat soil in this study is categorized as saprist, which has advanced weathering, where <1/3 volume before rubbing and colored very dark gray to black [12]. The soil texture of tidal land was classified as clay loam with a bulk density as relatively low. Soil pH of both soil types was categorized as very acidic (peat) to acid (tidal). The soil used from the tidal land contains pyrite that is found in the deep layer (65 cm from the soil surface). The macronutrient content of N, P, and K in peat soils ranges from moderate to very high, while in tidal is very low to very high. As expected, the C-organic content dan cation exchangeable capacity (CEC) in peat is very high and low in tidal. The very high C-organic content in peat soils can bind Fe and P are more available. Whereas on tidal soils that contain less C-organic content, Fe tends to bind with P that results in less availability of P [13]. Exchangeable-K on peat soils has a very high value due to the degree of decomposition and process of decaying of parent material, and it might be caused by a lower permeability [14].

Table 1. Soil characteristics in peat and tidal land

Soil properties	Peat	Tidal
Soil physic		
Texture (%)		
- Sand	-	1
- Silt	-	55
- Clay	-	44
Bulk density (g cm^{-3})	0.28	0.54
Soil chemistry		
Soil pH (H_2O 1:5)	4.5	5.4
C-organic (%)	14.35	1.23
Total-N (%)	0.26	0.17
N-NH_4^+ (ppm)	94.4	21.1
N-NO_3^- (ppm)	20.8	56.5
Available-P (ppm)	199.1	8.1
Total-P (mg $100g^{-1}$)	41	98
Total-K (mg $100g^{-1}$)	120	82
Soluble-Fe (ppm)	15.3	664.5
Exchangeable cations		
Na (me $100g^{-1}$)	0.81	1.29
K (me $100g^{-1}$)	1.39	0.14
Ca (me $100g^{-1}$)	3.12	1.75
Mg (me $100g^{-1}$)	2.23	0.87
CEC (me $100g^{-1}$)	60.26	10.33

3.2. Change of soil pH

Soil pH is an essential indicator of soil chemical properties and is closely related to the level of nutrient availability for plants [15]. Soils with low pH (acidity) tend to make some nutrients needed by plants unavailable. The results of the analysis showed that the application of ameliorant affected changes in soil pH. The pH on peat soils significantly increased with the application of dolomite (p1), chicken manure (p2), and oyster mushroom baglog waste (p5) compared to control (p0) as 57%, 36%, and 30%, respectively. Whereas, in tidal soils, dolomite (p1), chicken manure (p2), paddy husk charcoal (p4), and oyster mushroom baglog waste (p5) the increment as 43%, 40%, 21%, and 40%, respectively (Figure 1). Increased pH of peat soil and tidal swamps significantly occurred in dolomite treatment due to it has a pH of 8.4 that contains Ca and Mg, where these two elements replaced the position of H^+ on the surface of the colloid so it can neutralize soil acidity [16]. The application of dolomite can elevate soil pH as long as the pH is below 4.5 [17]. Chicken manure can increase the pH of peat soil significantly, also. It might be caused by an ion-exchange reaction that occurs when the OH^- terminal of Al or Fe^{2+} hydroxyl oxide is replaced by organic anions of decomposed fertilizer products such as malate, citrate, and tartrate [18]. Besides, it is caused by the presence of basic cations in chicken manure that release during microbial decarboxylation [19]. Paddy husk ash and paddy husk charcoal were not able to significantly increase the pH of the peat soil compared to the control. It is might because the dose is too low. A significant increase in soil pH occurred at a dose of 50 ton ha^{-1} of paddy husk charcoal [20]. Besides, peatlands have a large buffering capacity, so the ameliorant (paddy husk ash and paddy husk charcoal) dose must be increased.



Note: p0 = control; p1 = dolomite; p2 = chicken manure; p3 = paddy husk ash; p4 = paddy husk charcoal; p5 = oyster mushroom baglog waste.

Figure 1. Change in soil pH in peat and tidal land due to different ameliorant application. Error bars represent standard deviation. Mean values followed by the same letter are not significantly different based on the Duncan's Multiple Range Test (DMRT) at a significance level of 5%.

3.3. Plant Growth

3.3.1. Plant height. The results of the analysis showed that the application of ameliorant affected plant height (table 2). A significant increase in paddy plant height on peat soil was showed by the application of dolomite (p1), paddy husk ash (p3), and oyster mushroom baglog waste (p5). Meanwhile, in tidal land were dolomite (p1), chicken manure (p2), paddy husk ash (p3), and baglog waste of oyster mushrooms (p5). The highest plant height was showed in oyster mushroom baglog waste (p5) application, were 73.13 and 88.85 cm on peat and tidal soils, respectively. It is because the N content in the oyster mushroom baglog waste of 0.6-0.8% [21], has met the N needs for paddy plants so that it can increase the height of paddy plants. Nitrogen plays a role in the growth of lowland paddy plants. If the plants are deficient in this nutrient, plant growth will be inhibited [22]. The application of dolomite is also able to increase the height of paddy plants in peat and tidal soils. The application of dolomite can increase the soil pH then improve nutrient balance so that nutrients can be absorbed by plants [23]. Dolomite supplies of OH^- to the soil solution that reacts with H^+ causes the H^+ level to decrease so that the soil pH increases [24]. The correlation test proves that an increase in soil pH is followed by an increase in plant height (r = 0.666).

The application of paddy husk ash can increase the height of paddy plants. Paddy husk ash is the result of further pyrolysis from burning paddy husk charcoal showing the SiO_2 content reaches 80-90%. Due to that, paddy husk ash pH is very high that stimulates an increase in the pH of the acidic soil [25]. The adding of chicken manure and paddy husk charcoal did not show a significant increase in plant height. Applications of organic ameliorants in paddy and maize at doses of 5 and 10 ton ha^{-1} showed symptoms of nitrogen and phosphorus deficiency and stunted growth on peat soils [26]. In peat soils, H^+ ions are available in large quantities, so that the application of organic ameliorants should be combined with materials that provide OH^- ions.

Table 2. Paddy growth in peat and tidal soils due to difference of ameliorant application

Type of soil	Treatment	Plant height (cm)	Tiller number
Peat	Control	58.4^{a}	7^{a}
	Dolomite	70.3^{bcd}	11^{c}
	Chicken manure	65.6^{ab}	10^{bc}
	Paddy husk ash	67.9^{bc}	8^{a}
	Paddy husk charcoal	63.5^{ab}	8^{ab}
	Oyster mushroom baglog waste	73.1^{cd}	12^{c}
Tidal	Control	65.2^{ab}	7^{a}
	Dolomite	87.2^{e}	9^{ab}
	Chicken manure	76.6^{d}	9^{ab}
	Paddy husk ash	73.2^{cd}	7^{a}
	Paddy husk charcoal	70.3^{bcd}	8^{ab}
	Oyster mushroom baglog waste	88.9^{e}	10^{bc}

Note: Mean values followed by the same letter in the same column are not significantly different based on the Duncan's Multiple Range Test (DMRT) at a significance level of 5%.

3.3.2. Tiller number. The results of the analysis showed that the application of ameliorant on peat and tidal soils affected the tiller number of the paddy plant. Significant differences were shown in the treatment of dolomite (p1), chicken manure (p2), and baglog waste of oyster mushrooms (p5), whereas in tidal land, only oyster mushroom baglog waste (p5) was able to increase the tillers number (table 2). Oyster mushroom baglog waste and dolomite can increase the soil pH of peat soil more than other treatments because both contain sufficient Ca to overcome soil acidity problems and increase nutrients, especially N [27]. The increase in soil pH has a positive correlation with the availability of nutrients for plants. The addition of ameliorant effects on n physical and chemical properties (soil acidity and redox potential), and the activity of microorganisms in the soil [28]. Those are increasing nutrient availability.

Nitrogen is needed in large quantities to support vegetative growth. It is an essential building block for chlorophyll in photosynthesis [29]. The role of the P is to stimulate the growth of new leaves and increase the rate of photosynthesis as well as stimulate root growth, flower, and fruit formation. Meanwhile, the K nutrient can also compose the meristem tissue in plants, resulting in a fall resistant plant. When nutrient needs were met, plants can produce a large number of productive tillers. The greater the number of productive tillers can have implications for an increase in the yield of paddy plants. Table 2 shows that dolomite treatment significantly affects the tiller number on peat soils, but it has no significant effect on tidal land. It can be caused by the ameliorant dose has not affected the number of tillers in paddy plants, or the nutrient content in the soil has met the needs of the paddy plant [30]. It also applies to the treatment of chicken manure, paddy husk ash, and paddy husk charcoal.

3.4. Paddy Yield

3.4.1. Dry weight. The results of the variance analysis showed that all ameliorant treatments significantly affected the dry weight of paddy plants on both peat and tidal soils, except for the treatment of paddy husk ash on tidal soil. Plant dry weight had a positive correlation with the tiller number of paddy plants (r = 0.618). The greater the number of tillers, the higher the dry weight of the plant. Plant dry weight indicates nutrient absorption and accumulation in the plant body. Sufficient nutrients available lead to better cell division, elongation, and maturation that increase plant volume and weight [29].

3.4.2. Weight of 100 grains. The results of the analysis of variance showed that the application of ameliorant on peat and tidal soil s affected the weight of 100 grains of paddy. Significant differences are shown in the treatment of dolomite (p1), chicken manure (p2), paddy husk ash (p3), and baglog waste of oyster mushrooms (p5), whereas in tidal soil, only chicken manure was able to increase the weight of 100 grains paddy (table 3). Treatment of paddy husk charcoal did no effect on the weight of 100 grains of paddy on both peat and tidal soils. It could be due to the low C/N ratio of the husk charcoal. The low C/N ratio causes the decomposition rate to be slow so that the supply of nutrients is slower in the soil. Waterlogging on peat and tide soils can also slow down the rate of decomposition [31].

Table 3. Paddy yield in peat and tidal soils due to the difference of ameliorant application

Type of soil	Treatment	Dry weight (g pot^{-1})	Weight of 100 grain (g)	Productivity (ton ha^{-1})
Peat	Control	29,25^{a}	1,92^{a}	2,26^{a}
	Dolomite	49,96^{cd}	2,14^{bcd}	4,56^{bcd}
	Chicken manure	66,33^{ef}	2,28^{d}	5,75^{ef}
	Paddy husk ash	45,58^{bc}	2,17^{bcd}	4,45^{bcd}
	Paddy husk charcoal	53,06^{cde}	2,03^{abc}	5,44^{def}
	Oyster mushroom baglog waste	85,69^{g}	2,16^{bcd}	5,69^{ef}
Tidal	Control	33,04^{ab}	1,96^{ab}	3,64^{b}
	Dolomite	57,02^{cde}	2,10^{abcd}	4,01^{bc}
	Chicken manure	63,73^{def}	2,22^{cd}	6,17^{f}
	Paddy husk ash	43,53^{bc}	2,14^{bcd}	4,56^{bcd}
	Paddy husk charcoal	62,12^{def}	2,09^{abcd}	4,93^{cde}
	Oyster mushroom baglog waste	74,73^{fg}	2,08^{abcd}	5,80^{ef}

Mean values followed by the same letter in the same column are not significantly different based on the Duncan's Multiple Range Test (DMRT) at a significance level of 5%.

3.4.3. Productivity. The results of the analysis of variance showed that the application of ameliorant on peat and tidal soils affected the dry grain weight of paddy. The significant increase in dry grain weight of paddy on peat soil was shown in all ameliorant treatments, while in tidal soils were chicken manure (p2), paddy husk charcoal (p4), and oyster mushroom baglog waste (p5). The percentage increase in paddy productivity on peat soils was 50%, 61%, 50%, 58%, and 60% in the treatments of dolomite (p1), chicken manure (p2), paddy husk ash (p3), paddy husk charcoal (p4), and oyster mushroom baglog waste (p5), respectively. Whereas, in tidal land was 41%, 26%, and 37% in the treatment of chicken manure (p2), paddy husk charcoal (p4), and oyster mushroom baglog waste (p5), respectively (table 3). On peat soils, all treatments affect paddy productivity variables, where the treatment given can increase the pH value and can also bind the solubility of Al and Fe in the soil with organic matter so that the availability of P elements in the soil increases. Deficiency of the nutrient P is very high in peat and tidal soils, with the reduction in Al and Fe reaction, more P is available in the soil. The element P is an essential factor for optimal paddy plant growth and increased paddy productivity [32]. In tidal soils, only dolomite and paddy husk ash treatment did no effect on paddy productivity variables. Dolomite raises soil pH but provides limited nutrients for plants for plant growth [32].

Whereas in paddy husk ash, the nutrient content is less than that of roasted husk charcoal, so that the generative phase growth cannot provide optimal results [25].

4. Conclusions

Application of chicken manure and oyster mushroom baglog waste showed a high increase in soil pH, and paddy growth and production in peat and tidal land. Those ameliorants contain complete nutritions that improve soil productivity to support plant growth. Chicken manure and oyster mushroom baglog waste are organic substances that can bind the toxicity Fe in peat and tidal land, thus induce the increment of soil pH.

References

[1] Mulyani A, Sarwani M 2013 Karakteristik dan potensi lahan sub optimal untuk pengembangan pertanian di Indonesia *J. Sumberdaya Lahan* **7**(1) 47–55. (http://dx.doi.org/10.21082/jsdl.v7n1.2013.%25p)
[2] Abduh A M, Annisa W 2017 Interaction of paddy varieties and compost with flux of methane in tidal swampland *J. Trop Soils* **21**(3) 179. (http://dx.doi.org/10.5400/jts.2016.v21i3.179-86)
[3] Rinaldi P S, Akromah Z N, Ramadhan H, Husna S, Syamsudin D L, Panggabean P B 2019 Physical and chemical analysis of land in forest peat swamp in resort pondok soar, Tanjung Puting National Park, Central Kalimantan. *The 2nd International Conference on Tropical Silviculture: Forest Research and Innovation for Sustainable Development* (*Bogor*) vol 394 *IOP Conference Series: Earth and Environmental Science*. (doi:10.1088/1755-1315/394/1/012037)
[4] Palansooriya K N, Shaheen S M, Chen S S, Tsang D C W, Hashimoto Y, Hou D 2020 Soil amendments for immobilization of potentially toxic elements in contaminated soils: A critical review. *Environment Internasional* 134 (https://doi.org/10.1016/j.envint.2019.105046)
[5] Susilawati H L, Pramono A, Setyanto P, Inubushi K 2020 Soil amelioration on peat and its effect on methane (CH_4) emission and rice yield 2020 *In: Tropical Wetlands - innovation in mapping and management- Proceedings of the International Workshop on Tropical Wetlands: Innovation in Mapping and Management* (*Banjarmasin*) (Taylor & Francis).
[6] Ar-Riza, Alkasuma 2008 Pertanian lahan rawa pasang surut dan strategi pengembangannya dalam era otonomi daerah (in Bahasa) *J. Sumberdaya Lahan* **2**(2) 95-104
[7] Sufardi S, Syakur S, Karnilawati K 2013 Amelioran organik dan mikoriza meningkatkan status fosfat tanah dan hasil jagung pada tanah Andisol (in Bahasa) *J. Agrista* **17**(1) 1-48
[8] Jamilah J, Safridar N 2012 Pengaruh dosis urea, arang aktif, dan zeolit terhadap pertumbuhan dan hasil padi sawah (*Oryza sativa* L.) (in Bahasa) *J. Agrista* **16**(3) 153-62
[9] Septiyana, Sutandi A, Indriyati L T 2017 Effectivity of soil amelioration on peat soil and rice productivity. *J. Trop Soils* **22**(1) 15-22 (doi: 10.5400/jts.2017.22.1.15)
[10] Sulaiman A A, Sulaeman Y, Minasny B 2019 A framework for the development of wetland for agricultural use in Indonesia *Resources* **8(1)** 34. (https://doi.org/10.3390/resources8010034)
[11] Duncan D B 1995 *Multiple range and multiple F tests* (International Biometric Society Biometrics) pp 1-42 (doi: 10.2307/3001478)
[12] Staff S S 2010 *Keys to soil taxonomy* Soil Conserv Serv (Department of Agriculture and Natural Resources Conservation Service) p 167
[13] Ready K R, Kadlec R H, Flaig E, Gale P M 1999 Phosphorus retention in streams and wetlands: A review *Critical Reviews in Environmental Science and Technology* **29**(1) 83-146 (https://doi.org/10.1080/10643389991259182)
[14] Mohd Tajuddin S A, Rahman J A, Abd Rahim N H, Radin Mohamed R M S, Abduh Algheethi A A S 2018 Influence of potassium on sapric peat under different environmental conditions. *4th International Conference on Civil and Environmental Engineering for Sustainability* (*Lankawi)* vol 140 *IOP Conference Series: Earth and Environmental Science* (doi

:10.1088/1755-1315/140/1/012073)
[15] Neina D 2019 The role of soil pH in plant nutrition and soil remediation *Applied and Environmental Soil Science* **2019**. (https://doi.org/10.1155/2019/5794869)
[16] Aryanti E, Yulita Y, Annisava A R 2017 Pemberian beberapa amelioran terhadap perubahan sifat kimia tanah gambut (in Bahasa) *J. Agroekoteknologi* **7**(1) 19-26. (http://dx.doi.org/10.24014/ja.v7i1.2245)
[17] Basuki B, Sari V K 2020 Efektifitas dolomit dalam mempertahankan pH tanah Inceptisol perkebunan tebu blimbing djatiroto *Bul Tanam Tembakau, Serat Minyak Industri* **11**(2) 58-64. (doi: 10.21082/btsm.v11n2.2019.58−64)
[18] Dikinya O, Mufwanzala N 2010 Chicken manure-enhanced soil fertility and productivity: Effects of application rates *J. Soil Sci Environ Manag* **1**(3) 46-54
[19] Nätscher L, Schwertmann U 1991 Proton buffering in organic horizons of acid forest soils *Geoderma* **48** 93-106. (https://doi.org/10.1016/0016-7061(91)90009-I)
[20] Persaud T, Homenauth O, Fredericks D, Hamer S 2018 Effect of rice husk biochar as an amendment on a marginal soil in Guyana *World Environ* **8**(1) 20-5 (doi:10.5923/j.env.20180801.03)
[21] Rosmayanti, Bakti D, Rahmawati N, Ridwansyah 2020 Efforts to increase production sweet potato as raw materials Kaya Beta Karoten flour by using compost baglog mushroom waste *Abdimas Talent* **5**(1) 102–7.
[22] McGrath J M, Spargo J, Penn C J 2014 *Soil fertility and plant nutrition* vol 5 In: Encyclopedia of Agriculture and Food Systems (San Diego: Elsevier) pp166-84
[23] Brown T T, Koenig R T, Huggins D R, Harsh J B, Rossi R E 2008 Lime effects on soil acidity, crop yield, and aluminum chemistry in direct-seeded cropping systems *Soil Sci Soc Am J* 72(3) 634-40 (https://doi.org/10.2136/sssaj2007.0061)
[24] Cherian C, Arnepalli D N 2015 A critical appraisal of the role of clay mineralogy in lime stabilization *Int J Geosynth Gr Eng* **1** 8. (doi: 10.1007/s40891-015-0009-3)
[25] Adha I 2011 Pemanfaatan abu sekam padi sebagai pengganti semen pada metoda stabilisasi tanah semen (in Bahasa) *J. Rekayasa* **15**(1) 33-40
[26] Maftu'ah E, Maas A, Syukur A, Purwanto B H 2013 Efektivitas amelioran pada lahan gambut terdegradasi untuk meningkatkan pertumbuhan dan serapan NPK tanaman jagung manis (*Zea mays* L. var. *saccharata*) (In Bahasa) *Indones J Agron* **41**(1) 16-23. (https://doi.org/10.24831/jai.v41i1.7071)
[27] Sendi H, Mohamed M TM , Anwar MP, Saud HM 2013 Spent mushroom waste as a media replacement for peat moss in Kai-Lan (*Brassica oleracea* var *Alboglabra*) production *Sci World J* 2013. (http://dx.doi.org/10.1155/2013/258562)
[28] Juhrian J, Yusran F H, Wahdah R and Priatmadi BJ 2020 The effect of biochar, lime, and compost on the properties of acid sulphate soil *J. Wetl Environ Manag* **8**(2) 157-73. (http://dx.doi.org/10.20527/jwem.v8i2.249)
[29] Barker A V., Pilbeam D J 2016 *Handbook of plant nutrition* (Taylor & Francis)
[30] Masganti M, Nurhayati N, Yuliani N 2017 Peningkatan produktivitas padi di lahan pasang surut dengan pupuk P dan kompos jerami padi (in Bahasa) *J. Tanah dan Iklim* **41**(1) 17-24
[31] Toma Y, Takakai F, Darung U, Kuramochi K, Limin S H, Dohong S 2011 Nitrous oxide emission derived from soil organic matter decomposition from tropical agricultural peat soil in central Kalimantan, Indonesia *Soil Science Plant Nutrition* **57**(3) 436-51. (https://doi.org/10.1080/00380768.2011.587203)
[32] Masganti. Teknologi inovatif pengelolaan lahan subotimal gambut dan sulfat masam untuk peningkatan tanaman pangan *Pengembangan Inovasi Pertanian* (in Bahasa) **6**(4) 187-97. (http://dx.doi.org/10.21082/pip.v6n4.2013.187-197)