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UTILIZATION OF STEEL SLAG IN IMPROVING SOIL CHARACTERISTICS

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ABSTRACT

Steel slag is a by-product in the process of refining iron by Blast Furnace (BF) or Electric Arc Furnace (EAF). This by-product can be used for various fields such as construction, industry and agriculture. This study aimed to observe the use of steel slag in agriculture as fertilizer, lime and ameliorant in the soils. The method used was the experimental design used steel slag in several level: 1,2,3,4,5,6,7,8 to 9% to change several soils characteristics of Ultisols and Andisols. The result showed that steel slag increased pH, decreased P=fixation and P-retention and increased available P ini Ultisols and Andisols. This result of this research is expected contributed to government who would like to improve characteristics in sub optimal soils. The novelty is the using of steel slag in agriculture that not been used widely yet.

Keywords: Fertilizer, Lime , Ameliorant.

1. INTRODUCTION

Steel slag is a by-product of the iron refining process in the steel industry. The refining process produces pure steel, with steel slag as the by-product. As a by-product, steel slag is waste, conversely it still can be utilized for various uses, such as the cement industries. road constructions, bridges and buildings (Rondon-Quintana et al., 2018). Steel slag also can be used for agriculture purposes, due to containing Ca, Mg and Si, makes this material has the potentiality to be used as fertilizer and/or ameliorant. The presence of these elements in steel slag comes from the iron refining process which requires the addition of various naterials. Steel is then produced from iron ore (iron oxide) which processed in heating furnace (Wright, 2016). The materials introduced into heating furnace are iron ore itself, carbon, lime-calcium oxide, calcium carbonate, calcium magnesium carbonate. The reation causes the waste materials from ores (among them silica and other material) to be converted into slag (silicate). These processes and reactions occur continuously. Iron ore is refined into steel slag, and steel slag is produced as a by-product.

Some content in steel slag like Ca and Mg are the potential element increasing pH due to in soil reaction can realise some OH^{-1}. This OH^{-1} will contribute in increasing soil pH. Ion OH^{-1} will react with Al^{+3} forming a solid form of $Al(OH)_3$. Silicate in steel slag can function as anion that also react with Al forming aluminum compound of $Al(OH)_3$ that unhazardous.

The steel slag produced in chunk form, which must be processed into fine sizes in order to applied for agricultural uses. The finer size leads to a larger surface area, allows the reactions faster. Fine sized particles are expected to react faster than larger-sized particles. This fine particle is expected to release the nutrient and ameliorant contained in steel slag to improve soil characterics including increase the pH value, reducing or releasing P-fixation and increasing available P which is often a probem in various soils including Ultisols and Andisols.

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Ultisols is one of the most widely soils order in Indonesia. It is estimated around 48 miljoen hectare or almost 25% of Indonesia's total area, distributed in almos all Indonesian islands (Subagyo et al, 2004). Its wide distribution makes Ultisols very potential in the development of dryland agriculture in Indonesia. Most of the Ultisols develops from acidic parent materials, result in acid soils with low pH. Cation exchange capacity (CEC), basic cations, base saturation (BS) and organic matter content are also low. However, some acid cations like Al dan Fe are high, which tend to fix phosporus, makes the P-fixation is high and available P is high (Tan, 2011). Efforts that can be made to improve Ultisols characteristics are by applying the ameliorants that can increase the soil pH, and reduce the level of Al and Fe. This improvement further can decrease P-fixation and increase available P. Calsium in steel slag can be contribute as lime in increasing soil pH. Silicate in steel slag act as anion and replace phosphate that fixed by aluminum. It will decrease P-fixation and increase available P.

Andisols is the soils derived from ash of volcanic eruption. This soil considered as a productive soil due to have preferable soil physics characteristics like low bulk density (Soil Survey Staff, 2014) high water holding capacity and high porosity. Some excellent chemical characteristics are also prominent like high organic carbon content and high base saturation. However, it has an inhibition factor in case of high P retention. This characteristic is due to the presence of of noncrystalline minerals like allophane, imogolite and ferrihydrite.

Research related to observe the influence of steel slag in improve chemical characteristics of Ultisols is steel rare to be published. This study was done to compile and report the influence of steel slag on several soil chemical characteristics of Ultisols and Ultisols.

2. LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Steel slag in general contain Ca and silica, and other components like Fe, Al, Mg and P (Seti´en et al., 2009). In smalller amounts there are heavy metals (Das et al., 2007). However, the presence of Al, as toxic element, must be considered. The presence of other metals like Fe_2O_3 and MnO even though only in micro quantities, have to be taken into account. Other micro elements found are chromium (Cr), zinc (Zn), barium (Ba), strontium (Sr), copper (Cu), zircon (Zr), vanadium (V), niobum (Nb), lead (Pb), nickel (Ni), tin (Sn), molybdenum (Mo), rubidium (Rb), arsenic (As), cadmium (Cd), uranium (U), bromium (Br), cerium (Ce), cobalt (Co), lanthanum (La), ytirum (Y), thorium (Th), bismuth (Bi), gallium (Ga).

Several countries such as Japan, Germany, the United States, Korea, China has used steel slag for agriculture as lime and fertilizer. The consideration they used in applying steel slag is due to Ca and Mg content that can increase soil pH and due to their function as essential elements. Steel slag is also contain Si as a non-essential nutrient hat can increase the photosynthetic process and plant health and essential for *Gramineae* plants such as rice, corn and sugarcane (Matichenkov and Calvert, 2002). The element Si can help in releasing retained-P also in Andisols and fixed-P in Ultisols (Qafoku et al., 2004)

Steel slag in Indonesia has been used limited in research field, for example for soybeans (*Glycine max* L. Merr.) and sorghum (*Sorghum vulgare* Pers.). Lime can increase pH of Ultisols from pH of 5.5 to 6.5. Steel slag used as lime gave a better result on soybean and sorghum production than liming with calcium carbonate (Suwarno, 1999). Guano phosphate combined with steel slag and dolomite. Applying steel slag to to *Brassica chinensis* on Andisols gave the better result compared to with magnesium phosphate and super phosphate. Pot experiments showed that guano phosphate with steel slag is better than guano phosphate with calcite on sorghum plants grown on Ultisols. The experimental results showed that both steel slag and calcite increased the effectiveness of guano phosphate. Guano phosphate is also more effective when combined with steel slag than when combined with calcite (Suwarno et al., 2002).

The effect of steel on peat soils has also been investigated that increased the productivity of some plant like oil palm. The steel slag was used to examine the use of steel as an ameliorant. The result infoemed that steel slag can increase and absorbing water, protect plant from hydrophobicity (Winarna, et al, 2016). Another research was conducted in Sanggau Regency, West Kalimantan, showed that steel slag improved the productivity of dry milled rice grain around 65-96%. Another research was reported by Setiko et al. (2015) showed that steel slag increased the number of tillers, productive tillers and yields of rice crops even until the third planting period. The plantations located in peatland were used to observe the use of steel slag as an amandment and found that steel slag can increase pH and improve the abilty of soils in absorbing water, prevent iydrophobicity (Winarna, et al, 2016).

The use of steel slag in Ultisols and Andisosl have not reported widely. These soil orders are variable-charged soils with different characteristics. The charge of variable charge soils are depends on soil pH and ionic concentration and the composition of several charges component including allophane and imogolite of mineral materials.

Ultisols derived normally from sediment parent materials, where the rain fall was high enough to leach the cations, and especially to leach the clay particle. This soil had low base saturation and high acidity. Aluminum content in Ultisols fixed the phosphate result in lowered available P in Ultisols. In the other hand, Andisols has high phosphate retention that more than 85% (Soil Survey Staff, 2014). The P retention is the inhibition of Andisol in inreasing plant productivities Steel slag can add some negative charge in Andisols and increase availabel P as mention by Van Ranst (1995). Meanwhile Ultisols has problem in fixation P.

The research conducted in gathering information of steel slag in improving soil characteristics, in this case in Ultisols and Andisols

3. METHODOLOGY

The research was done in experimental design of Completely Randomized Design. Ultisols was retrieved from Citatah District Bandung Barat Regency of West Java Province, Indonesia. Soils in this area is classified as Ultisols. Andisols was brought from the area around foot slope of Mt. Tangkuban Parahu in Lembang, West Java, Indinesia. The soils was taken from the upper 30 cm in several spot and mixed homogenously. The steel slag was obtained from PT Krakatau Steel Indonesia. The steel slag was powdered and analysed in the Laboratory of Center for Research and Development of Mineral and Coal Technology. The incubation process and the analyses of soils before and after incubation were done in the Laboratory of Soil Physics and Soil Fertility and Plant Nutrition of Faculty of Agriculture Universitas Padjadjaran. The analyses of pH used pH meter, P-fixation and available P used Flamephotometer, following Van Reewijk (2011)

Experimental design was Completely Randomized Design with evelent dosages treatment as follow:

A = Control (without steel slag)
B = 1% steel slag sized 1,7 µm
C = 2% steel slag sized 1,7 µm

D = 3% steel slag sized 1,7 µm
E = 4% steel slag sized 1,7 µm
F = 5% steel slag sized 1,7 µm
G = 6% steel slag sized 1,7 µm
H = 7% steel slag sized 1,7 µm
I = 8% steel slag sized 1,7 µm
J = 9% steel slag sized 1,7 µm
K = 5 % of steel slag 200 mesh sized

The differentiation between treatments were analysed using Duncan Multiple Range Test (DNMRT).

The soils used were 1 kg, mixed homogenously with the steel slag according to the dosages. They were then put into the polybag, watered to field capacity and incubated for two months. After two months the soils were analysed to observe the change of soil characteristics, in this case: pH, P-fixation and available P.

4. RESULT AND DISCUSSION

4.1 Soils and steel slag characteristics prior to incubation

The soils and steel slag were analysed before treatment, and the result is presentented in Table 1 and 2. Table 1 informed that the parameters observed was unfavorable for plant. The pH was acid, the P-fixation was very high and available P was low. In the other hand total P was high. There was the indication that available P can be increase due to P reserve (total P) was high enough, which can be released into available P if soil reaction supported.

Table 1. Chemical characteristic of the soil before treatments

No	Parameters	Unit	Value	Criteria*)
Ultisols				
1.	pH H_2O	-	5,10	acid
2.	P-fixation	%	76.44	very high
3.	Available	$mg.kg^{-1}$	6.92	low
4.	Total P	%	25.23	high
5.	Organic Carbon	%	1,7	low
6.	Total N	%	0,12	low
7.	CEC	$Cmol. Kg^{-1}$	12,90	low
8.	Ca	$Cmol. Kg^{-1}$	0.80	low
9.	Mg	$Cmol. Kg^{-1}$	0,52	low

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10.	K	Cmol. Kg^{-1}	0,24	low
11.	Na	Cmol. Kg^{-1}	0,20	low
12	Base Saturation	%	13,56%	low
13	Al-dd 1,33	Cmol. Kg^{-1}	1.33	high
Andisols				
1	pH H_2O	-	5.49	acid
2	P-retention	%	88.6	high
3	Available	mg.kg^{-1}	9.41	low
4	Total P	%	25.4	high
5	Organic Carbon	%	4.43	high
6	Total N	%	1.2	high
7	CEC	Cmol. Kg^{-1}	32.6	high
8	Ca	Cmol. Kg^{-1}	4.2	high
9	Mg	Cmol. Kg^{-1}	0.8	low
10	K	Cmol. Kg^{-1}	0.2	low
11	Na	Cmol. Kg^{-1}	0.1	low

Note:
*) The criteria was according to Soil Research Institute (2009).

Table 2. Analyses of steel slag before treatments

No.	**Parameters**	**Unit**	**Value**
1.	SiO_2	%	12.50
2.	CaO	%	42.00
3.	MgO	%	6.00
4.	P_2O_5	%	0.50
5.	FeO	%	0.81
6.	Water content	%	0.00
8.	Bulk density	g cm^{-3}	1.70

Tabel 2 informed that the silicate content is high (12.5%). During incubation periode, the silicate was expected to release the silicate anion to replace phosphate anion that fixed by aluminum, adding some available P to the soil. Ottinger (2013) inform that silicate can function as anion in releasing P-fixation. The concentration of Ca was very high (42.00%) which can function as lime to increase the pH and also help in releasing P-fixation, and also increase available P (Mengel, 1987).

4.2 Utilization of Steel Slag in Changing Characteristics of Ultisols

4.2.2 Soil pH

The result of soil pH is presented in Table 3. It was shown that all of the treatments significantly different with the control (without steel slag). The increasing pH was seen starting from the dosage of 1% steel slag, and increased with the increasing dosages. The highest pH reached at the highest dosage of 9% steel slag. Treatment with 200 mesh sized also increased the pH value, significantly different with control, and not signicantly different with the treatments of 2 to 9% of sized dosages.

Table 3. Soil pH value after 2 month incubated with several dosages steel slag

Treatments	**Soil pH**
A= Control (without steel slag)	5,10 a
B= 1% steel slag sized 1,7 µm	6,85 b
C= 2% steel slag sized 1,7 µm	7,23 bc
D= 3% steel slag sized 1,7 µm	7,47 cd
E= 4% steel slag sized 1,7 µm	7,41cd
F= 5% steel slag sized 1,7 µm	7,43 cd
G= 6% steel slag sized 1,7 µm	7,63 cde
H= 7% steel slag sized 1,7 µm	7,79 de
I= 8% steel slag sized 1,7 µm	7,83 de
J = 9% steel slag sized 1,7 µm	7,96 e
K= 5 % of steel slag 200 mesh sized	7,63 cde

Note: Same lettters indicates no difference of the value between the treatments with Duncan Multiple Range Test 5%

The increasing pH showed that Ca and Mg content in steel slag function as lime in the soils. The reaction of Ca and Mg soils in increasing pH are the series of reaction, where several OH^{-1} ions are released. The ions contributed to the increasing of soil pH value. The sized encouraged the acceleration of the reaction, where the finer the particle the fast the reaction happened. Finer particle with higher surface area contributed in releasing OH^{-1} ions and increasing pH value.

4.2.2 P-fixation

The result of P-fixation after incubation is presented in Table 4. The P-fixation prior to the treatment was 76.44% (Table 1). steel slag was expected can deacrease the fixation. After two months incubation, the change of of fixation can be seen in the Table 4. The data in Table 4 showed that the treatments with several dosages of steel slag not significantly decrased the P-fixation. However, The tratments of 2 and 3% of steel slag showed the lowest P-retention eventhoght they were not significantly decrease with control.

Table 4. P-fixation after 2 month incubated with several dosages steel slag

Treatments	**P-fixation (%)**
A= Control (without steel slag)	74,95 ab
B= 1% steel slag sized 1,7 µm	74,98 ab
C= 2% steel slag sized 1,7 µm	71,54 a
D= 3% steel slag sized 1,7 µm	71,38 a
E= 4% steel slag sized 1,7 µm	77,54 ab
F= 5% steel slag sized 1,7 µm	79,58 ab
G= 6% steel slag sized 1,7 µm	78,26 ab
H= 7% steel slag sized 1,7 µm	85,54 b
I= 8% steel slag sized 1,7 µm	84,99 b
J = 9% steel slag sized 1,7 µm	85,80 b
K= 5 % of steel slag 200 mesh sized	76,46 ab

Note: Same lettters indicates no difference of the value between the treatments with Duncan Multiple Range Test 5%

Fixed phosphorus is one of inhibition phosphorus available for plant. Fixed phosphorus happened in the soils if there are ions with positive charge like Al^{+3} fixed the negative phosphate anions ($H_2PO_4^{-1}$). It can be seen in Ultisols, include Ultisols in this research with active Aluminum 1.33 cmol.kg^{-1} (Table 1). The silicate (SO_4^{-1}) content in steel slag was expected can

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replace phosphate in the fixed aluminum site, and reduce P-fixation and subsequently converted into available P. In thsis case, silicates in steel slag were not strong enough to replace P-fixation in aluminum.

The interesting phenomenon was seen that actually P-fixation was decreased with 2 and 3% dosages, eventhought the decreased were unsinificantly different with control and with 1% dosage. It indicate that the expected reaction of silicate from steel slag succed in releasing fixed P in Al. Increasing dosage was expected decreased more fixed P, but factually increasing dosage till 9% even increased P-retention that unsignificantly different with control. Decreasing P-fixation was more difficult than increasing soil pH. The difficulties in changing soil reactions was explained by the soil buffer capacity, that defend the soil condition against the amendment. The theory related to the mechanism of phosphate fixation is that phosphate ions in soil soluiom are deposited and unavailable for plant.

4.2.3 Available P

The result of availbe P after incubation is presented in Table 5. The available P prior to the treatment was 6.92 $mg.kg^{-1}$ (Table 1). steel slag was expected can increase available P. After two months incubation, the change available P can be seen in the Table 5.

Table 5. Available P after 2 month incubated with several dosages steel slag

Treatments	Available P ($mg.kg^{-1}$)
A= Control (without steel slag)	9.54a
B= 1% steel slag sized 1,7 µm	14,12 c
C= 2% steel slag sized 1,7 µm	13,42 bc
D= 3% steel slag sized 1,7 µm	12,55 bc
E= 4% steel slag sized 1,7 µm	11,81 bc
F= 5% steel slag sized 1,7 µm	13,09 bc
G= 6% steel slag sized 1,7 µm	12,77 bc
H= 7% steel slag sized 1,7 µm	11,57 ab
I= 8% steel slag sized 1,7 µm	11,88 bc
J = 9% steel slag sized 1,7 µm	12,27 bc
K= 5 % of steel slag 200 mesh sized	13.37 bc

Note: Same lettters indicates no difference of the value between the treatments with Duncan Multiple Range Test 5%

4.3 Utilization of Steel Slag in Changing Characteristics of Andisols

4.3.1 Soil pH

The change of soil pH is presented in Table 6. All of the treatment different significantly after treated with steel slag, means that steel slag contributed several ion OH^{-1} to the soils that supported the increasing pH (Devnita 2019). However, the increasing was not linear with the increasing dosages.

Table 6. Soil pH value after 2 month incubated with several dosages steel slag

Treatments	**Soil pH**
A= Control (without steel slag)	5.49a
B= 1% steel slag sized 1,7 µm	6.54c
C= 2% steel slag sized 1,7 µm	6.31b
D= 3% steel slag sized 1,7 µm	5.72cd
E= 4% steel slag sized 1,7 µm	6.32b
F= 5% steel slag sized 1,7 µm	6.33b
G= 6% steel slag sized 1,7 µm	6.12ab
H= 7% steel slag sized 1,7 µm	6.17ab
I= 8% steel slag sized 1,7 µm	6.82d
J = 9% steel slag sized 1,7 µm	6.12ab
K= 5 % of steel slag 200 mesh sized	6.64c

4.3.2 P-retention

The change of P retention is presented in Table 7. Steel slag was expected decreased the retained P. Table 7 informed that steel slag significantly decreased the P retention in any dosages. However the decreasing was not linear with the dosages. Phosphorus is retained by positive charge site in Andisols that can formed by alumino silicate minerals of apllophane, imogolite and ferrihydrite (Devnita et al, 2017a). The positive charge of these minerals retained the negative charge of phosphate ions (Devnita et al, 2017 b) The silicate ions from steel slag was expected replaced the retained P in Andisols and it can be seen have decreased P-retention to less than 10%.

Table 7. P-retentiom after 2 month incubated with several dosages steel slag

Treatments	**P-retenton (%)**
A= Control (without steel slag)	83.09 c
B= 1% steel slag sized 1,7 µm	70.25 a
C= 2% steel slag sized 1,7 µm	76.62 b
D= 3% steel slag sized 1,7 µm	78.72 b
E= 4% steel slag sized 1,7 µm	74.93 ab
F= 5% steel slag sized 1,7 µm	73.85 ab
G= 6% steel slag sized 1,7 µm	74.95 ab
H= 7% steel slag sized 1,7 µm	70.03 a
I= 8% steel slag sized 1,7 µm	73.70 b
J = 9% steel slag sized 1,7 µm	73.54b
K= 5 % of steel slag 200 mesh sized	75.61

Note: Same lettters indicates no difference of the value between the treatments wibth Duncan Multiple Range Test 5%

4.3.3 Available P

Table 7. Available P after 2 month incubated with several dosages steel slag

Treatments	**Available P (mg.kg $^{-1}$)**
A= Control (without steel slag)	13.23 a
B= 1% steel slag sized 1,7 µm	22.31 abc
C= 2% steel slag sized 1,7 µm	23.70 abc
D= 3% steel slag sized 1,7 µm	17.66 ab
E= 4% steel slag sized 1,7 µm	16.49 ab
F= 5% steel slag sized 1,7 µm	49.72 c
G= 6% steel slag sized 1,7 µm	42.97 bc
H= 7% steel slag sized 1,7 µm	18.59 ab

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I= 8% steel slag sized 1,7 µm	30.25 abc
J = 9% steel slag sized 1,7 µm	25.57 abc
K= 5 % of steel slag 200 mesh sized	31.27 abc

Note: Same lettters indicates no difference of the value between the treatments with Duncan Multiple Range Test 5%

5. CONCLUSION

5.1. Conclusion

- Steel slag can be used to improve soil characteristics of Ultisols and Andisols
- The dosages ranged from 1 to 9% with various result

5.2 Limitation

- Access to gain steel slag is uneasy
- Steel slag need further process to be applied to soils

5.3. Suggestion

- Collaboration with government is needed to socialized the usage of steel slag for agriculture, focused on maginal soil that need to be improved their characteristics.

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