Amelioration of Ultisols in West Java Indonesia with microparticle of steel slag

R Devnita¹, R Hudaya¹, M F Rosana², A Sandrawati¹, and H Hazarika³

¹ Faculty of Agriculture, Universitas Padjadjaran, Jatinangor-Sumedang 45363, Indonesia
² Faculty of Geology, Universitas Padjadjaran, Jatinangor-Sumedang 45363, Indonesia
³ Faculty of Engineering, Kyushu University, Nishi-ku Fukuoka 819-0396 Japan

Email: rina.devnita@unpad.ac.id

Abstract. Researchs used steel slag as ameliorant had proven that it can improve some soil chemical characteristics. The objective of this research was to investigate the influence of microparticle of steel slag in improving some soil chemical characteristics of Ultisols. The treatments were arranged in Completely Randomized Designed (CRD) with ten treatments: control (without steel slag), steel slag in coarse particle (mesh), and 1-9% (in weight percentage) of microparticle of steel slag. The soil and the treatments were repeated three times and incubated for four months and then be analyzed the change of soil characteristics due to the amelioration after 1, 2, 3, and 4 months of incubation period. The result showed that amelioration of Ultisols with microparticle of steel slag improved several soil characteristics like increased pH, CEC, available P, and exchangeable basic cations like Ca, Mg, K and Na. The treatments did not decrease the P-fixation, however they increased available P.

1. Introduction
Steel slag is the by-product in the steel industry that contain several nutrients and can function as lime [1]. Many countries like Japan, Germany and the United State had utilized steel slag as a soil ameliorant for years [2]. Meanwhile the usage of steel slag is more focus to other than agriculture, like for road construction [3] and building materials [4]. The utilization of steel slag for agriculture in Indonesia is still rare, but some had been used in the plantation [5]. Steel slag can increase pH [6], therefore is suitable for increasing pH in acid soil which widely occur in Indonesia like Ultisols. Calcium and magnesium in steel slag serve as lime and release OH⁻ to decrease the acidity [7]. Besides, the steel slag contains silicate and iron that may also donate some silicon and iron ions as nutrients source [8] [6] and as negative charge source of OH⁻ ion as another advantages in increasing soil pH [6].

Particle size contribute in accelerating the soil reaction. The finer the particle caused the bigger the surface area and the more effective the reaction [9]. Most of the reaction in the soil happened in the colloidal size, less than 1 μm [9]. Nanoparticle as the colloidal size had been widely developed for several application in Agriculture [10]. To be used as soil ameliorant, steel slag has to be powdered to have the expected reaction. However, a hard and massive material like steel slag is difficult to be ground to nano sized particle, therefore was ground to micro particle. The usage of microparticle of steel slag as amelioration was an alternative innovation in improving Ultisols characteristics.
2. Materials and Methods
The research was arranged in experimental design where the soils (Ultisols) were incubated with steel slag (according to the treatments) for four months. The soils then be analyzed before and after incubation to know the influence of steel slag to the change of soil characteristics. Ultisols were taken compositely from the depth of 0-60 cm at several points and mixed evenly to have the homogeneity. Prior and after to the treatments, the soils were analyzed for pHw, pH KCl, delta pH, total nitrogen, organic carbon, basic cations, cation exchange capacity, base saturation, exchangeable Al and Fe with certain procedure [11], otherwise measuring the P concentration in the solution by the colorimetric technique, and P-retention determined with Blakmore procedure [11].

The steel slag was gained from PT. Krakatau Steel Indonesia. The size of the steel slag was ranged from gravel (2-4 mm) to pebble (4-64 mm) according to scale by Wentworth [12]. The gravel-size was dominant, and the pebble-size was dominated by 4-10 mm. The steel slag be ground with bed milling machine in Print-G Laboratory of Universitas Padjadjaran to the size of 1.7 µm.

The research used a completely randomized experimental design with 11 treatments and three replications. The treatments were the percentage of the microparticle steel slag (1.7 µm) against the soil weight (w/w) viz. without steel slag, 1, 2, 3, 4, 5, 6, 7, 8 and 9% of microparticle of steel slag and 5% of steel slag in mm size. The soils (each 1 kg) and the treatments were mixed evenly and put into a 2 kg size plastic bag and then watered to the soil field capacity. The soils and steel slag were incubated for four months. During incubation period, the soils were taken after one, two, three and four months of incubation to be analyzed the change of soil characteristics due to the amelioration. The mean differences of the change soil characteristics were tested with Duncan’s New Multiple Range Test.

3. Results and Discussions

3.1. Data of the Soils and Steel Slag Prior to the Treatments
The parent materials of the soils were volcanic rock. The area had 15% slope and was at 448 m above sea level and had C climate according to Oldeman [13]. No gravel, pebble or rock fragments found at the surface. The top soil (0-30 cm) chemical characteristics data is presented in Table 1.

| Nr | Parameters                  | Unit   | Value |
|----|-----------------------------|--------|-------|
| 1  | pH H₂O                      |        | 5.26  |
| 2  | pH KCl                      |        | 4.2   |
| 3  | Organic carbon              | %      | 1.70  |
| 4  | Total nitrogen              | %      | 0.12  |
| 6  | P-fixation                  | %      | 76.44 |
| 7  | Available P                 | ppm P  | 6.92  |
| 8  | Potential P                 | mg.100 g⁻¹ | 15.23 |
| 9  | Available basic cations     |        |       |
|    | Exchangeable Ca             | cmol.kg⁻¹ | 0.80  |
|    | Exchangeable Mg             | cmol.kg⁻¹ | 0.52  |
|    | Exchangeable K              | cmol.kg⁻¹ | 0.24  |
|    | Exchangeable Na             | cmol.kg⁻¹ | 0.20  |
| 10 | Cation Exchange Capacity    | cmol.kg⁻¹ | 12.6  |
| 11 | Base Saturation             | %      | 13.56 |
| 12 | Exchangeable acidity        | cmol.kg⁻¹ | 1.57  |
| 13 | Exchangeable Al             | cmol.kg⁻¹ | 1.33  |
| 14 | Exchangeable H              | cmol.kg⁻¹ | 0.24  |
| 15 | Al saturation               | %      | 28.16 |
The data informed that the pH was slightly acid (5.26), the organic carbon content was low (1.7%). The high P-fixation (76.44%) made the available P was low (6.92 mg kg\(^{-1}\)). The cation exchange capacity of the soil was low (13.56 cmol.kg\(^{-1}\)). The basic cation of Ca, Mg, K, and Na were all in low concentration (0.80, 0.52, 0.24 and 0.20 cmol.kg\(^{-1}\) respectively), made the base saturation was also low (13.56%) as the prerequisite of Ultisols that have to be less than 35% [14].

The exchangeable aluminum was medium (1.34 cmol kg\(^{-1}\)), however it was not the requirements to fulfill the Ultisols by Soil Survey Staff [14] as often be percepted by many people. The presence of clay illuviation as requested by Soil Survey Staff [14] was clearly presented in texture analysis (Table 2). It can be seen that clay content increased from the elluvial horizon (average 47.3%) to illuvial Bt horizon (average 70.3%). The increasing of clay content from elluvial to illuvial that more than 1.2 times informed the existence of argillic horizon which together with the base saturation of less than 35%, classified the soils as Ultisols according to Soil Survey Staff.

### Table 2. Particle size analysis result from every horizon

| Horizon | Depth (cm) | Sand (%) | Silt (%) | Clay (%) |
|---------|------------|----------|----------|----------|
| Ap1     | 0-15       | 5        | 49       | 46       |
| Ap2     | 15-28      | 5        | 49       | 46       |
| AB      | 28-50      | 5        | 45       | 50       |
| Bt1     | 50-80      | 5        | 35       | 60       |
| Bt2     | 80-107     | 2        | 73       | 75       |
| Bt3     | 107-140    | 2        | 76       |          |
| BC      | 140-170    | 2        | 85       |          |
| BC      | 170-200    | 2        | 84       |          |

The characteristics of steel slag are presented in Table 3. The pH of the steel slag was very high (11.8), and was expected can increase the soil pH. The high pH value of steel slag [15] compared several steel slag resulted in pH ranged from 10.3-12.5. However the CEC if steel slag was very low (2.3 cmol kg\(^{-1}\)). It can be understood, as the steel slag was neither clay nor organic matter.

### Table 3. Steel slag characteristics

| Nr | Parameters | Unit           | Value |
|----|------------|----------------|-------|
| 1  | pH         | -              | 11.3  |
| 2  | CEC        | cmol kg\(^{-1}\) | 2.3   |
| 3  | CaO        | %              | 46.65 |
| 4  | MgO        | %              | 14.80 |
| 5  | K\(_2\)O   | %              | 0.31  |
| 6  | Na\(_2\)O  | %              | 0.21  |
| 7  | SiO\(_2\)  | %              | 12.83 |
| 8  | FeO        | %              | 10.73 |
| 9  | Al\(_2\)O\(_3\) | %       | 9.75  |
| 10 | TiO\(_2\)  | %              | 1.22  |
| 11 | MnO        | %              | 1.76  |
| 12 | V\(_2\)O\(_5\) | %        | 0.37  |
| 13 | Pb         | mg kg\(^{-1}\) | 13    |
| 14 | Cr         | mg kg\(^{-1}\) | 190   |
| 15 | Cd         | mg kg\(^{-1}\) | <0.001 |
CaO (46.65%) was the highest content in steel slag, followed by MgO (14.8%). These oxides of calcium and magnesium were fathomed act as lime to release OH\(^{-}\) ions to the soils. The SiO\(_2\) content was also high (12.83%) which can release some Si and OH\(^{-}\) to the soil. The other content like FeO and Al\(_2\)O\(_3\) were also high. These contents must be aware due to the possibility to increase the acidity by releasing H\(^+\) and the possibility to fixed the phosphate by Al\(^+\) and Fe\(^+\) ions. Other contents were the heavy metals like Pb, Cd and Cr that must be avoided but they were there as the steel slag content. However, the low concentrations of the heavy metals were expected will not give the negative influences to the soils.

![Figure 1. Particle size analyzer result of steel slag](image)

3.2. Soil pH and CEC

The data on Table 4 informed that the pH value increased by various treatments of steel slag. The increasing were consistent during the incubation period from 1 to 4 month. The increasing of pH was due to the influence of the high pH of steel slag (11.3) as informed in Table 3. Steel slag contributed the OH ion to increased soil pH. In this research, the increasing ranged from 1.73-2.86 unit. Another research found that increasing pH was 0.9-2.00 unit [15], in the other hand the increasing pH was only 0.70-0.86 unit [6]. The various dosages of steel slag increased the pH, however the increasing of the dosages were not always in line with the increasing of pH. It was also found that 5% of steel slag the size of 200 mesh (127 µm) which was the coarsest size in these treatments was not significantly different with 5% of steel slag size 1.7 µm.

| Treatments            | pH     | CEC (cmol.100g\(^{-1}\)) |
|-----------------------|--------|--------------------------|
|                       | 1      | 2       | 3      | 4      | 1      | 2       | 3      | 4      |
| without steel slag    | 5.19 a | 5.10 a  | 5.08 a | 5.42 a | 12.59 a| 12.66 a | 12.52 a| 12.65 a|
| 5% steel slag, 127 µm | 7.69 c | 7.63 cde| 7.59 cd| 7.70 cd| 15.92 cde| 16.20 cde| 17.90 bcd| 16.25 d|
| 1% steel slag, 1.7 µm | 7.12 b | 6.85 b  | 7.24 bc| 7.15 b  | 13.84 b | 13.86 b | 17.21 b | 13.97 b |
| 2% steel slag, 1.7 µm | 7.59 c | 7.23 bc | 7.29 bc| 7.46 c  | 15.08 c | 14.40 b | 17.58 b | 14.15 b |
| 3% steel slag, 1.7 µm | 7.59 c | 7.47 cd | 7.13 b | 7.51 c  | 15.12 c | 15.48 c | 17.84 b | 15.32 c |
| 4% steel slag, 1.7 µm | 7.73 cd| 7.41 cd | 7.48 bcd| 7.69 cd | 15.45 c | 15.76 d | 17.89 b | 15.35 c |
| 5% steel slag, 1.7 µm | 7.72 cd| 7.43 cd | 7.61 cd| 7.76 d  | 16.26 de| 16.74 e | 17.92 bcd| 16.20 d |
| 6% steel slag, 1.7 µm | 7.69 cd| 7.63 cde| 7.57 cd| 7.84 d  | 16.35 de| 16.96 e | 17.94 bcd| 16.75 d |
| 7% steel slag, 1.7 µm | 7.73 cd| 7.79 de | 7.54 bcd| 7.81 d  | 16.38 de| 16.89 e | 18.21 cd | 16.89 d |
| 8% steel slag, 1.7 µm | 7.70 cd| 7.83 de | 7.72 cd| 7.83 d  | 16.39 de| 16.89 e | 18.50 d | 16.87 d |
| 9% steel slag, 1.7 µm | 7.87 d | 7.96 e  | 7.85 d | 7.88 d  | 16.42 e | 16.92 e | 18.61 d | 16.87 d |

Note: Same letters indicate no difference of value among the treatments with Duncan New Multiple Range Test 5 %
Table 4 also informs that steel slag increased soil CEC. Steel slag’s CEC was low (2.3 cmol kg⁻¹) as shown in Table 3, therefore it will not contribute a lot to the increasing of soil CEC. The increasing were predicted due to the increasing of pH, where the increasing of pH will increase the negative charge and increased the CEC. In tropical soils, the increasing of pH, increased the CEC [16]. The higher the pH of a soil, the faster the soil CEC will increase with time. The relative proportion of acidic and alkaline or basic ions on the exchange sites determines a soil’s pH value.

3.3. P-fixture and Available P
The influence of steel slag on P fixation and available P are reported in Table 5. The data showed that P fixation were not in line with available P after treated with steel slag. The P fixation showed the increasing with steel slag treatments, which should be decrease. It can be seen from P-fixture value in control or without steel slag (74.81%) that increased to 94.20% (7% steel slag of 1.7 µm). These increasing occurred in the treatment of 1 to 9% steel slag and were consistent from after incubation 1 month to after 4 months incubation. At this point, the treatments with steel slag had no influence because it increased P fixation, whereas it should decrease. However, data of available P showed the opposite.

| Treatments                  | P fixation (%) | Available P (mg kg⁻¹) |
|-----------------------------|---------------|-----------------------|
|                             | 1  | 2  | 3  | 4  | 1  | 2  | 3  | 4  |
| without steel slag          | 74.21 b | 74.95 ab | 77.04 a | 72.24 ab | 73.5 ab | 9.54 a | 8.66 a | 11.11 a |
| 5% steel slag. 127 µm        | 75.81 b | 76.46 ab | 80.71 a | 71.19 ab | 9.75 ab | 13.37 bc | 14.92 c | 13.51 bc |
| 1% steel slag. 1.7 µm        | 76.53 b | 74.98 ab | 76.44 a | 67.68 a | 10.00 ab | 14.12 c | 14.07 c | 14.97 d |
| 2% steel slag. 1.7 µm        | 69.35 a | 71.54 a | 76.91 a | 69.31 a | 13.31 bc | 13.42 bc | 18.44 d | 15.92 d |
| 3% steel slag. 1.7 µm        | 69.70 a | 71.38 a | 78.09 a | 75.39 ab | 12.74 bc | 12.55 bc | 15.31 c | 13.77 bc |
| 4% steel slag. 1.7 µm        | 84.45 c | 77.54 ab | 77.06 a | 79.21 ab | 14.23 bc | 11.81 bc | 12.87 bc | 13.53 bc |
| 5% steel slag. 1.7 µm        | 84.36 c | 79.58 ab | 82.01 ab | 79.52 ab | 14.94 bc | 13.09 bc | 10.63 ab | 13.28 ab |
| 6% steel slag. 1.7 µm        | 83.67 c | 78.26 ab | 88.47 b | 78.64 ab | 17.66 c | 12.77 bc | 12.99 bc | 12.30 ab |
| 7% steel slag. 1.7 µm        | 94.20 e | 85.54 b | 81.65 ab | 78.07 ab | 17.69 c | 11.57 ab | 14.53 c | 12.80 ab |
| 8% steel slag. 1.7 µm        | 90.18 d | 84.99 b | 84.92 b | 82.96 ab | 17.91 c | 11.88 bc | 13.11 bc | 11.83 a |
| 9% steel slag. 1.7 µm        | 89.04 d | 85.80 b | 87.96 b | 85.82 b | 18.37 c | 12.27 bc | 10.86 ab | 12.02 ab |

Note: Same letters indicate no difference of value among the treatments with Duncan New Multiple Range Test 5 %

All of the treatments with steel slag increased available P compared to control. The increasing were consistent from the period of 1 month after incubation to 4 months after incubations. The available P after 1 month of incubation with the increasing of dosage, however the dosage of 6-9% of steel slag had no significant difference. High content of P intended to overcome available P in Ultisols [17]. The incubation period to four months made the differentiation of available P. The lower dosage (1-3% steel slag of 1.7 µm) showed the increasing of available P after four month of incubation. However, the higher dosage (4-9% steel slag of 1.7 µm) showed) the decreasing of available P. It was predicted that the decreasing related to the increasing of P-fixture.

3.4. Basic Cations (Ca, Mg, K and Na)
The influence of steel slag on the exchangeable of basic cations like Ca, Mg, K and Na is reported in Table 6. The data showed the interesting phenomena of applying steel slag to Ultisols. All of the cations increased their exchangeable by the application of steel slag, and the increasing were in line with the dosage of steel slag. Compared to all basic cations, the highest increasing (0.15-0.50 cmol kg⁻¹) found in exchangeable Ca. It can be understood since calcium (in CaO) was the highest content in steel slag (46.65%) as can be seen in Table 3, followed by magnesium (MgO 14.80%), potassium (K₂O 0.31%),
and sodium (Na₂O 0.21%). Steel slag was an alternative byproduct to replace limestone or dolomite since steel slag contains useful elements as lime and fertilizer [18].

### Table 6. The influence of steel slag to exchangeable Ca and Mg on Ultisols

| Treatments       | Exchangeable Ca (cmol/kg⁻¹) | Exchangeable Mg (cmol/kg⁻¹) |
|------------------|-----------------------------|-----------------------------|
|                  | 1  | 2  | 3  | 4  | 1  | 2  | 3  | 4  |
| without steel slag | 0.81 a | 0.80 a | 0.80 a | 0.79 a | 0.50 a | 0.50 a | 0.51 a | 0.51 a |
| 5% steel slag, 1.7 µm | 1.24 d | 1.45 c | 2.03 d | 1.64 d | 0.60 bcd | 0.64 c | 0.92 bcd | 0.61 e |
| 1% steel slag, 1.7 µm | 0.96 b | 1.20 b | 1.38 b | 1.32 b | 0.56 b | 0.57 b | 0.86 b | 0.54 b |
| 2% steel slag, 1.7 µm | 1.05 c | 1.23 b | 1.85 c | 1.47 c | 0.58 bc | 0.61 bc | 0.87 b | 0.55 bc |
| 3% steel slag, 1.7 µm | 1.21 d | 1.29 b | 2.01 d | 1.49 c | 0.60 bc | 0.63 c | 0.89 bc | 0.56 cd |
| 4% steel slag, 1.7 µm | 1.23 de | 1.44 c | 2.02 d | 1.49 c | 0.60 bc | 0.65 c | 0.90 bc | 0.57 d |
| 5% steel slag, 1.7 µm | 1.28 e | 1.52 d | 2.17 e | 1.80 e | 0.64 cde | 0.71 d | 0.93 bcd | 0.61 e |
| 6% steel slag, 1.7 µm | 1.26 e | 1.69 e | 2.23 ef | 1.99 e | 0.64 cde | 0.71 d | 0.96 cd | 0.62 e |
| 7% steel slag, 1.7 µm | 1.27 f | 2.00 f | 2.28 f | 2.14 f | 0.65 de | 0.71 d | 0.97 cd | 0.92 e |
| 8% steel slag, 1.7 µm | 1.28 f | 2.07 f | 2.29 f | 2.14 f | 0.68 e | 0.73 d | 0.97 d | 0.62 e |
| 9% steel slag, 1.7 µm | 1.31 f | 2.07 f | 2.30 f | 2.17 f | 0.70 e | 0.75 d | 0.98 d | 0.62 e |

Note: Same letters indicate no difference of value among the treatments with Duncan New Multiple Range Test 5%

It is interesting to watch that the exchangeable Ca was continues to occur till four months after incubation period. Such high calcium in steel slag kept on adding Ca content to the soil during the incubation period and increased the exchangeable Ca. The same phenomenon were not be found in exchangeable Mg although its content was quite high. It can be due to magnesium released from steel slag was not as fast and as much as calcium.

For potassium and sodium, the low percentage of their content in steel lag made not much increased in their exchangeable K and Na during incubation period (Table 7). However, the highest dosage of treatment (9% steel slag, 1.7 µm) showed the increasing of exchangeable sodium by the increasing of incubation period. Not much the increasing of potassium and sodium after be treated with steel slag [1].

### Table 7. The influence of steel slag to exchangeable K, and Na on Ultisols

| Treatments       | Exchangeable K (cmol/kg⁻¹) | Exchangeable Na (cmol/kg⁻¹) |
|------------------|-----------------------------|-----------------------------|
|                  | 1  | 2  | 3  | 4  | 1  | 2  | 3  | 4  |
| without steel slag | 0.19 a | 0.23 a | 0.23 a | 0.20 a | 0.20 a | 0.20 a | 0.20 a | 0.20 a |
| 5% steel slag, 127 µm | 0.31 c | 0.28 c | 0.31 bc | 0.27 cd | 0.30 c | 0.25 b | 0.26 b | 0.26 c |
| 1% steel slag, 1.7 µm | 0.24 b | 0.24 b | 0.25 b | 0.22 ab | 0.22 b | 0.22 b | 0.22 b | 0.21 a |
| 2% steel slag, 1.7 µm | 0.24 b | 0.26 bc | 0.27 b | 0.23 ab | 0.23 b | 0.22 b | 0.29 b | 0.21 a |
| 3% steel slag, 1.7 µm | 0.26 b | 0.27 c | 0.27 b | 0.23 ab | 0.24 b | 0.24 b | 0.31 bc | 0.23 b |
| 4% steel slag, 1.7 µm | 0.26 b | 0.29 c | 0.31 b | 0.25 bc | 0.26 bc | 0.26 b | 0.35 c | 0.24 b |
| 5% steel slag, 1.7 µm | 0.33 d | 0.33 d | 0.34 c | 0.28 cd | 0.30 de | 0.30 c | 0.42 d | 0.26 c |
| 6% steel slag, 1.7 µm | 0.35 d | 0.33 d | 0.35 c | 0.29 de | 0.31 de | 0.35 c | 0.43 d | 0.28 d |
| 7% steel slag, 1.7 µm | 0.36 e | 0.38 e | 0.38 d | 0.30 e | 0.32 de | 0.38 c | 0.43 d | 0.34 e |
| 8% steel slag, 1.7 µm | 0.36 e | 0.39 e | 0.41 d | 0.33 f | 0.33 de | 0.41 c | 0.43 d | 0.39 f |
| 9% steel slag, 1.7 µm | 0.37 e | 0.39 e | 0.43 d | 0.34 f | 0.35 e | 0.42 c | 0.44 d | 0.46 g |

Note: Same letters indicate no difference of value among the treatments with Duncan New Multiple Range Test 5%

### 4. Conclusion

Microparticle of steel slag can be used as ameliorant in Ultisols due to can improve some soil characteristics like in increasing pHw, CEC, available P, exchangeable basic cation especially Ca and Mg. Although the P-fixation cannot be decreased, the available P increased. The increasing of exchangeable basic cations also improving soils characteristics in serving nutrients for plant growth.
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