Utilization and Improvement of Marginal Soils for Agricultural Development in Indonesia

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Abstract. Indonesia is a humid tropical country that has very intensive weathering of soils resulting acidic soils such as Oxisols and Ultisols. In swampland ecosystems, organic matters accumulated become peat soils or Histosols. Reclamation of shallow peat for agricultural land will induce the forming of acid sulfate soils (Sulfaquept and Sulfaquent). Due to low fertility soils, the three of above soils are classified as marginal soils and now they are used for agricultural activities and some of them are still in forests. The use of marginal soils should refer to land suitability whether it is retained as a forest or used as agricultural land. The development of agricultural commodities on marginal soils must consider soil characteristics and agro-climate conditions. Oxisols and Ultisols have characteristics of low pH, low organic C, low macro and micro nutrients. In areas where rainfall is higher than 2,000 mm/year and evenly distributed throughout the year, oil palm plantations can be well developed. Meanwhile in the rainfall between 1,750-2,000 mm/year, rubber, cacao, coffee plants can be cultivated. Agricultural development in acidic soils need to be followed by the addition of soil amendments such as organic materials, humic substances, lime, fly ash, steel slag as well as fertilizers. Acid sulfate soils have a pH value of around 3 due to pyrite oxidation and usually low macro and micro nutrient content. Acacia mangium plants as raw material for pulp and oil palm plantation can grow quite well if followed by application of fertilizers and appropriate soil amendments. Peat soils are very fragile ecosystem so that in the upstream area and peat dome, they must be retained as forests. Peat can be developed for Acacia crassicarpa, oil palm, and rubber plants with good water and fertilizer management. Thin peat underneath mineral soil from river sediments can be developed rice field.

Keywords: humic substances, marginal soils, soil ameliorant, water management.

1. Introduction
In general, Indonesia has a tropical monsoon type climate, featuring slight changes in seasons and temperatures, low winds, a high degree of humidity and periodic heavy rainfall. There are two Monsoons: East Monsoon or dry season running from May to September which is influenced by the Australian Continental air masses, and the West Monsoon or rainy season from December to March, which is influenced by the Asian Continental and Pacific Ocean air masses passing over the ocean. Temperatures are largely uniform throughout the year, i.e. between 22 until 27°C, with a uniform relatively humidity between 70 to 90 percent. The rainfall distributions vary between the regions, depending on topography, air mass movement, etc. Generally the country annual rainfall is relatively abundant and varies between 700 to 4,000 mm. On most area of Sumatra, Kalimantan and West Java,
the dry period is however not completely rainless, and there is still moisture over almost the whole year. The climax vegetation on this part of Indonesia is therefore typical rainforest vegetation, and the area enjoys optimum climatic condition for growing a wide range of crops. East Java, Nusa Tenggara and part of Sulawesi are much drier, and are covered by vast grasslands. However, in those less favored areas, rain fed agriculture for at least 4 to 5 months each year, while tree growth is almost continuous [1]. Oil palm plantations occupy the largest area, reaching 14.5 million ha spread across Sumatra, Kalimantan and Papua Islands. Then followed by rubber, sugar cane, cacao, coffee plantations, etc. Food crops that are widely available in Indonesia are 7.4 million ha of rice, followed by corn, soybeans, cassava, etc. Horticultural crop development is mostly done on fertile land, especially Andisols in the highlands.

Various types of soils indicate that Indonesia support many type of ecosystem, because soil characteristics that determine the type of soil are the results of interaction of some land ecosystem parameters. Generally, Indonesia has both land and marine ecosystems, in which the land ecosystems include wetland and dry land ecosystems. Those ecosystems can still be differentiated into some sub-ecosystems. Various types of ecosystem in the tropical and humid climate of Indonesia are responsible for luxuriant vegetation of tropical rain forests containing timber and other forest products. Within the forests grow a large variety of epiphytes, and many kinds of flowers, including the great number of orchids, various kinds of bamboo, rattan, palm trees, etc.

With a humid tropical climate, macro and micro nutrients in the soils are easily leached out and organic matter is easily decomposed so that the soil becomes acidic and poor of nutrients and organic matter. This condition causes most of the soils have a low soil fertility. These soils require good management and proper fertilization in order to provide high production. Soils of this nature are classified as marginal soils which include acidic soils, peat soils and acid sulfate soils. In order marginal soils can provide great benefits to the community for agricultural business, the selection of agricultural commodities must be appropriate by choosing commodities that are adaptive to the characteristics of the soil and agro-climate.

If marginal soils are used for forests, then forest growth is very good because the nutrient cycle the forest soil takes place in a balance between what is absorbed by the forest trees and the entry of nutrients from decomposed litter fall. Within this region make the flora of Indonesia completely different from the flora of the neighboring continents, Asia and Australia, as well as from the tropical areas within these. The richness of the Melanesian region of which Indonesia represents the major portion, is reflected in the accommodation of close to 40,000 species of plants or about 10 to 12 percent of the estimated number of global plant species. Those tropical rain forests are the host of various fauna species. According to [2], 12 percent of mammals, 17 percent of birds, and 17 percent of reptiles and amphibian species of the world are found in Indonesia. Marine ecosystems are even more diverse, whereas Indonesia lies in the middle of a global bull’ eyes. Dealing with such richness of flora and fauna, Indonesia is known as the world’s mega-biodiversity country.

In this paper, we will describe how to manage marginal soils in the form of acidic soils, peat soils and acid sulfate soils based on soil and climate characteristics and the author’s considerations during fieldwork. The description that will be explained includes the characteristics of the soil, soil improvement, selection of agricultural commodities, and management recommendations so that marginal soils can provide great benefits for humans while considering sustainability.

2. Materials and Method
This paper is written and summarized from various sources from several papers and other sources such as discussions in various seminar forums and Focus Group Discussion (FDG). Discussions and conclusions are based on the author’s experience during field surveys in various locations on acidic soils, peat soils and acid sulfate soils. The research studies have been carried out in various locations in Sumatra and Kalimantan Islands. For peat soils, the research study was carried out in Sumatra, such as in Jambi, Riau and South Sumatra. Meanwhile, for acid sulfate soils were carried out in South Kalimantan, Central Kalimantan and Jambi.
The agricultural commodities that the authors examine in acidic soils are rice, oil palm, rubber, and *Acacia mangium*. Likewise, for peat and acid sulfate soils, many research studies were carried out for the commodity *Acacia crassicarpa*, oil palm, and rubber, and rice. By linking the characteristics of soil, agro-climate, agricultural commodities and agricultural production, recommendations can be made to improve acidic soils, peat soils and acid sulfate soils. Then by connecting the soil and agro-climate will be recommended types of plants that can be recommended for each soil type in a particular agro-climate

3. Results and Discussion

3.1. Characteristic, problems, and management of acidic soils

Acidic soils are soils that have a pH of less than 5.5 in both dry and wet soils. According to Soil Taxonomy [3], acidic soils are mostly classified into Oxisols, Ultisols, and Inceptisols. The soils of Indonesia are dominated by Inceptisols, Ultisols, and Oxisols so that it can be said that soils in Indonesia are mostly acidic soils. The three orders scattered mainly at Sumatra, Kalimantan, Sulawesi, and Papua Islands occupying 73% of the land area (Table 1). The soils generally have low pH less than 5.5, low CEC, and low macro and micro nutrients. The soils are grown tropical-rain forest, plantations, and small area for food crops.

| Soil Order | Area (million ha) | Percentage | Areal Distribution          |
|------------|------------------|------------|----------------------------|
| Inceptisols| 59.69            | 31.99      | Sumatra, Kalimantan, Sulawesi, Papua, Java |
| Ultisols   | 54.20            | 29.05      | Kalimantan, Sumatra, Sulawesi, Papua |
| Oxisols    | 23.08            | 12.37      | Sumatra, Kalimantan, Papua |
| Entisols   | 14.54            | 7.79       | Sumatra, Kalimantan, Java, Nusa Tenggara |
| Histisols  | 11.89            | 6.37       | Sumatra, Kalimantan, Papua |
| Mollisols  | 9.75             | 5.23       | Java, Kalimantan, Sulawesi, Papua |
| Andisols   | 7.77             | 4.16       | Sumatra, Java               |
| Vertisols  | 3.40             | 1.82       | Central and East Java       |
| Spodosols  | 2.07             | 1.11       | Kalimantan                  |
| Alfisols   | 0.20             | 0.05       | Java, Nusa Tenggara, Sulawesi |
| Total      | 186.59           | 100.00     |                             |

Source: Soil Research Institute, 2006 [4].

The main problem with acidic soils is low pH and is followed by low levels of organic matter. To overcome these problems, the technique by addition of liming materials such as calcite, dolomite, steel slag, and fly ash. The choice of materials and how much is the dosage will be applied, depend on the soil properties such as exchangeable Al, initial pH, organic matter and soil texture as well as the crops that will be cultivated.

Most of acidid soils have very low soil organic matter content. As have been stated by many researchers, soil organic matter plays very important role in the soil ecosystem. Soil organic matter influenced soil physical, chemical and biological properties of the soil. Therefore lacking of soil organic matter will disturb many soil processes and inhibit plant growth. Addition of organic matter into the soil is one of best practice in agriculture. Organic matter addition can be accomplished in the forms of plant residues, manure, compost, and humic substances. Humic substance is the essence of organic matter. Example of the characteristic of humic substances is shown in Table 2. From the solubility characteristic in alkali or acid, humic substance can be divided into four category [5], namely: Fulvic (soluble in alkali and acid), Humic (insoluble in acid but soluble in alkali); Himatomelanic (soluble in alcohol), and Humin (insoluble in acid and alkali).
Table 2. Chemical characteristics of humic substances

| Parameter       | Unit | Value |
|-----------------|------|-------|
| C-ash           | %    | 28.54 |
| Ash content DTA | %    | 41.94 |
| Carbon          | %    | 29.76 |
| Nitrogen        | %    | 1.85  |
| C/N             | %    | 16.10 |
| Solid           | %    | 9.58  |

To improve the nutrients availability, fertilizers must be applied to the soils. However, because of soil properties and natural condition (low organic matter, low active clay therefor low CEC, and high rainfall), ordinary fertilizers are not enough. Special fertilizers technology is needed to overcome the problem of disadvantages in soil properties that cause low soil fertility. Soil analysis is one key success factor in determining the nutrients need in this particular soil. Another factor is special form of fertilizers both for macro and micro nutrients that will be added to the soil base on the soil analysis. The way of the fertilizers application is also very important in increasing the efficacy and the efficiency of the fertilizers.

The main plantations planted at those soils are oil palm, rubber, coffee, cacao, sugar cane, etc. The oil palm is planted in area where rain is fall all over the year with the rainfall at least 2,000 mm/year. Sumatra, Kalimantan, and Papua are the main Islands where oil palm is planted. Meanwhile in the rainfall between 1,750-2,000 mm/year, rubber, cacao, coffee plants can be cultivated. Beside rice, the other Indonesian main food crops are corn and cassava. The central corn plantation is Gorontalo Province of Sulawesi Island whereas the central for cassava is Lampung Province, Central Java, and East Java.

3.2. Characteristic, Problems, and Management of Peat Soils (Histosols)

Histosols are peat soils that developed from organic matters accumulated in swampy ecosystems. These soils have organic soil materials that extend from the surface to any depth if the organic soil material rests on fragmental material and the interstices are filled with organic materials or rest on a lithic or paralithic contact. The peat soils in Indonesia is very typical, because these soils developed from organic accumulation of the tropical rain forest, therefore their bulk densities are very low (about 0.05 - 0.40 g/cm³) and the content of the macro-nutrients for plant such as N, P, K, Na, Ca, Mg, and micro-nutrients such as Fe, Cu, Zn, Mn and others are very low. Related to these characteristics, plant cultivation on the peat soils need a lot of fertilizers.

Histosols occupy 6.37% of the total Indonesian land. These soils distributed at east seashore of Sumatera Island, Kalimantan, and Papua. Histosols are mostly grown lowland tropical forest. Some Histosols near the rivers have been reclaimed by local peoples for paddy field. Since 1980’s government opened some Histosols at Sumatra and Kalimantan Islands for transmigration of Java people for paddy field. In the first 5 years, the production was very high but in the next years the production decreased gradually and abandoned by farmers. In 1990’s some private companies used Histosols for forest plantation especially acasia.

Since the year of 70’s systematic reclamation of wetland ecosystem is intensified and extended for transmigration program and for plantation sponsored by the Indonesian government. The peak of the wetland reclamation activities was the implementation of Mega Rice Project 1 million hectares in Kalimantan. Recently among 6 million hectares that have been open up, about 3-4 million hectares wetland are degraded and abandoned due to among others acid sulfate. The degraded wetland are mainly in Kalimantan (ex Mega Rice Project) and Sumatra. Increasing demand of energy and depletion of fossil energy source increase the challenge to produce green energy materials. Improvement of degraded wetlands provides opportunity to produce green energy material in industrial scale. There are some possibility of technology that can be used for degraded wetland improvement, among others is using of steel slag for ameliorant.
Indonesian peat soils were developed from woody materials, have many disadvantages characteristic as compared to peat soils from temperate areas. Peat soils in Indonesia are very acid (pH < 4.00), have very low ash content that mean also very low in nutrient, have very low bulk density and contain a lot of phenolic compounds that are toxic to plants especially food crops. Since 1970’s government of Indonesia has reclaimed millions of hectares of peat lands as transmigration area, however most of the reclaimed area were failed due to many factors such as low fertility of the soils, unsustainable agricultural practice by transmigrant (burning the peat to increase soil fertility), water mismanagement etc. But nowadays, several private companies have been successfully open peat land for Acacia plantation. The key success of acacia plantations in peat lands are: good water management, fertility improvement of the soil through boiler ash addition and good fertilizer management.

Around 6 million hectares of Histosols have been exploited for rice field, plantation, and forest plantation. The use of wetland in Indonesia has been carried out since a long time before world war II, especially for agriculture activities in traditional manners. Some researches dealing with traditional agriculture on wetland ecosystem in Kalimantan and Sumatra have been conducted by some researchers such as [6, 7, 8, 9].

Peat can be developed for Acacia crassicarpa, oil palm, and rubber plants with good water and fertilizer management. Shallow peat underneath mineral soil from river sediments can be developed rice field. Farmers cultivate rice, rubber, coconut on the reclaimed swampy areas.

3.3. Characteristic, problems, and management of acid sulfate soils

Sulfaquents are soils without development that have specific characteristics i.e. have sulphidic materials within 50 cm of the mineral soil surface, or are permanently saturated with water and have in all horizons below 25 cm dominant hue that is neutral or blue than 10Y and color that change on exposure to the air. These characteristics indicate that the sulphidic materials are only stable below water table under reduced environment. If water table is lowered, the soil environment becomes aerated and the sulphidic materials are under oxidation condition and produced strong acid. Within such condition the Sulfaquents are converted to Acid sulfate Soils, whereas the acid should be neutralized before cultivation.

Considering steel slag has high pH and base cations such as CaO, MgO and contain of micro nutrients needed by plants such as Cu, Zn, Fe dan Mn, CS has good prospective for soil amendment in acid soils having low in Si, macro and micro nutrients. The soils can be meet in peat soil and degraded lowland such as acid sulfate soils. The soils have pH of about 3 so that plants can not grow normally. Efforts to utilize peat land for production of crops should be accompanied by soil amendments such as lime, fertilizers of NPK, sulfate salts such as Fe, Cu, Zn, etc. Considering the price of fertilizers and soil amendment are very high, efforts to utilize S for improvement of peat and acid sulfate soils are very attractive.

Utilization of steel slag for improvement of degraded wetland such ad acid sulfate soils is very important because these soils are widely spreading in Sumatra and Kalimantan Islands and having very low productivity. For example farmer in Delta Berbak, Jambi Province only obtained 1 ton/ha/ year. In acid sulfate soils which have very low pH (<3), solubility of Al ion in water is very high and become toxic for plants. The content of Al in the canal water can reach >100 ppm. Sumawinata et al 2008 showed that acid sulfate soil in Rantau Rasau, Jambi besides low pH also contained of very low macro and micro nutrients. Acid parent material and intensive leaching in very acid environment (pH <3) causing most Fe ion and other ions in the soils are leached. Improvement of acid sulfate soil by application of lime, macro and micro nutrients increase the rice production become 4-5 ton/ha [10].

Efforts to utilize slag for soil amendment in degraded acid sulfate soils have good prospect. However the real application in commercial scale are still very limited because of slag sizing and transportation problems. Therefore, researches for utilization of steel slag for improvement of degraded wetland to support biomass production are needed. Through this research collaboration we hope steel slag produced from Sumitomo Corporation can be used for improvement of degraded wetland in Indonesia in order to increase the income and poverty of farmers as well as for production of green energy materials. Steel slag approved as a silicate fertilizer by Ministry of Agriculture, Forestry, and Fisheries of Japan in 1955.
The type of steel slag commonly used as silicate fertilizer is blast furnace slag and this slag also called as calcium silicate slag.

Research on utilization of slag in Indonesia for rice cultivation mostly conducted in rice field at Java Island. Soils in Java Island develop from volcanic ash materials or soil develop from old sedimentary rocks contain of enough Si content. Soils in Java Island periodically still enriched with volcanic ash material from the explosion of volcano rich in Si. With the above reasons application of steel slag in Si rich soils did not significantly increase the production of rice. On the other hand, application of steel slag in the rice field at peat soils showed the prospective results. [12] showed that application of Indonesian electric furnace slag on peat soil significantly improved the availability of Si as well as increased soil pH, exchangeable Ca and Mg. On the other hand, it significantly decreased soil organic matter content, total N, and the availability of Fe, Mn, and Zn. Wetland rice grown on peat soil highly responded to the slag application. The number of productive tiller, number of panicle, and weights of filled and total spikelets were significantly raised with the slag application. Increasing the growth and yield of wetland rice after application of the slag was associated with increasing the availability of Si, soil pH, and exchangeable Ca and Mg. However, utilization of steel slag did not widely applied in the field because of particle size that difficult in application and transportation problems.

Acid sulfate soils actually have more complexes problem. Mostly, increasing soil pH does not enough to solve the problem. To overcome the problems in acid sulfate soils, several approaches have to be accomplished altogether. Improvement technology for acid sulfate soil include:

1. Fertilizer technology. Acid sulfate soils usually contain very low nutrient, because most of the nutrients are dissolved and then washed away due to very acid condition of the soils. Therefor special form of fertilizer is needed. The way the fertilizer is applied and when the fertilizer is applied also must be considered to overcome the extreme condition that lead to nutrients leaching.

2. Red soil application. Although several researches though that in acid sulfate soil, there is iron toxicity but actually that is not the case. This thinking maybe due to the fact that pH of acid sulfate soil is very low therefor the dissolution of iron will be very high and this will cause iron toxicity. Of course at the beginning of acid sulfate soil formation that will be the case, however in the long run, the dissolve iron will be washed away and this process continue for several years, and at last most of the iron will be depleted from the system leaving the soil deficient of iron. To add the iron into the acid sulfate soil, red soil that is rich of iron has to be added.

3. Lime application. As has been mention above, most of the nutrients in the acid sulfate soil have been washed away, that include Calcium and Magnesium. To add these nutrients into the soil, liming materials such calcite and or dolomite have to be applied in acid sulfate soil. Addition of the liming materials can also increase the pH of the soil so decreasing the acidity of the soil.

4. Water management. The low pH of acid sulfate soil was caused by the oxidation of pyritic sediment in the soil. The oxidation can occur if the pyritic sediment is exposed to the air. This can happen because mismanagement of surface water level in that area. This lead to over drainage in that area so the soil surface become too dry that lead pyrite oxidation. To prevent this oxidation, the pyritic sediment has to be inundated by water. Therefor water management is very important in preventing pyrite oxidation that cause soil acidification.

5. Planting system. As mention above, pyrite oxidation must be restricted, that mean pyritic sediment has to kept inundated by water. This lead to less choice of plant that can be cultivated in that area. Only crop that can live in always saturated or flooded condition that can be chosen such as paddy. In some places like in South Kalimantun, Banjarese People using multiple transplanting technique to plant their paddy.

Many areas of acid sulfate soils are developed for oil palm plantation, rubber, and Acacia mangium. Those plants still adapted with very acidic condition. Good water and fertilizer management are the key for successful of agricultural practices in acid sulfate soil.
4. Conclusions
The development of agricultural commodities on marginal soils especially acidic soils, peat soils, and acid sulfate soils must consider characteristics and agro-climate conditions of the soils. Oil palm and rubber are the most suitable for acidic soils. Peat soils can be developed for *Acacia crassicarpa*, oil palm, and rubber plants, rice, and horticulture. The most important of peat development for agriculture is water management and fertilization. Development of acid sulfate soils are prioritized for plantation such as oil palm and rubber. Development of rice and other food crops should be followed by high doses of fertilizers and liming.

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