Soil bioengineering for sustainable coffee farming in *Way Besai* sub-watersheds, Lampung, Indonesia

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Abstract. Soil bioengineering is part of vegetative land conservation activities, including covering all use of plants to maintain the carrying capacity of the land. The sustainability of coffee farming achievement in the upstream watershed area is closely related to the application of soil bioengineering technology. This study conducted to identify the recent studies of soil bioengineering technology and its application in coffee farming toward increasing the land productivity in the upstream watershed. The research location is a smallholder coffee plantation upstream of the Way Besay sub-watershed, spread over 3 sub-districts, Air Hitam, Way Tenong, and Sumber Jaya sub-District, West Lampung, Lampung, Indonesia. Coffee farmers as many as 167 people as respondents. The data analysis method used exploration of the applicability of soil bioengineering technology at the micro-level. The mapping of the role of soil bioengineering trace using the VosViewer tool. The results of the analysis show that the readiness level application of soil bioengineering technology in coffee farming includes the production and use of organic fertilizers made from local materials, the use of mulch as soil cover, agroforestry with a variety of tall canopy plants/MPTS, the planting of multiple cropping (planting various yielding crops), and plant diversification with alley planting. Soil bioengineering technology has a very high potential to increase land productivity to support sustainable coffee production in the upstream area of the Lampung watershed.

1. Introduction
Soil bioengineering is one of the one trusty method that is believed to be able to protect land from degradation. It could maintain the quality of the land carrying capacity in the long term. Soil bioengineering is land conservation technology with classified as vegetative combination treatment. Vegetative approach means using plant resources and their biomass as optimally as possible to maintain and restore land. Integrating ecologically vegetative treatments is meeting specific goals in restoring the waterfront, stream, bayou, levee, and shorelines, especially for slope structural requirements, environmental, and aesthetic. Primary goals of soil bioengineering systems generally include flood control, stormwater management, stabilization and aquatic life, riparian wildlife corridors, ecological connections, and recreation. Soil bioengineering is increasingly used worldwide, primarily focused on mechanical soil reinforcement provided by plant roots and the search for available indigenous plant species. Wooden structures and aboveground habitat improvements have been using as soil bioengineering measures in agricultural areas [1]. It is useful throughout the watershed [2].
Watershed ecosystems are usually divided into upstream, middle, and downstream areas. The upstream watersheds area bio-geographically is a conservation area. It has a higher drainage density, a slope of more than 15%, and the type of vegetation is generally forest stands [3]. Protection function for the entire watershed, fully depend on the upstream watershed planning, with considering the linkages through the hydrological cycle. The linkage between upstream and downstream determines very strong bio-geophysical behavior of water due to changes in landscape characteristics. Agricultural land in mountainous areas and around watersheds is very prone to degradation because of rainfall, run-off that encourages erosion, leaching, and landslides, to nutrient depletion due to intensive cropping patterns and monocultures. Thus, the trade-off between land sustainability with intensive agriculture seem could be caused the ecological decreasing function [4]. In other side, watershed ecosystem has ecological, socio-cultural, and economic value for human life and cannot be separated ecologically from the surrounding ecosystem area. Population growth drives the demand for land to agriculture production increase. Cash crop production activities massively expand including to the upstream watersheds area. Agricultural cultivation without regard to conservation methods, causing land productivity reduction and impact on ecosystem changes that lead to environmental degradation. Land use change in watersheds threaten the land capabilities. Intensive agriculture or settlements still find in in land with slopes of more than 30% without the soil and water conservation techniques adequately.

Adequate conservation techniques in one area of land may not necessarily be adequate in another. The selection of adequate conservation techniques in a plot of land is strongly influenced by biophysical factors (soil, topography, land use, rainfall, climate) of the land concerned. The types of soil and water conservation techniques available to choose from and apply from the lightest to the most severe. It includes the use of mulch, contour planting, contour cultivation, conservation tillage (no tillage, minimum tillage), spacing settings, planting in strips (strip cropping), and sequential planting (rotation). Land-use changed in upstream watersheds affected by planting cultivation patterns. Economic value of commodities choices is the basic driver in planting system. Cash crops such as coffee, pepper, cocoa, palm oil, rubber are favor’s commodities in surrounding forests and upstream watersheds.

Coffee is important cash crop for Indonesian, it involves more than 2,3 million farmer’s household. Most of coffee farming was smallholders, with small-scale economic runs. Coffee as worldwide trade export commodities has very strategic role to regional economic growth. Coffee farming production center in Lampung, Indonesia concentrated in West Lampung and Tanggamus. There were lying the National Park of Bukit Barisan Selatan, sources of the two biggest rivers called Way Sekampung and Way Tulang Bawang. Sub-watersheds of Way Besai is the upstream of Way Tulang Bawang watersheds located in West Lampung that the coffee production center area farm.

It was reported that Way Besai sub-watershed has decreased forest land cover by 48% for over a 30 year period (1970 – 2000). The results of the study showed that 23.62% of the research area was categorized as normal soil erosion level, 42.98% light level, 14.57% moderate level, 15.38% heavy level and 3.45% very heavy. An area of 45% of the area with coffee plantation land cover experienced erosion rates in the light to very heavy category in all ranges of slopes and soil types. It seems that monoculture coffee plantations cause the soil layer to be very easily eroded by surface run-off due to the absence of ground cover under the coffee plant canopy. Smallholder plantations, which are mostly conventionally managed dominantly located on sloping topography with an average age of plants are over 25 years [5].

Changes occur because of high community activity in monoculture farming and seasonal crops. Therefore, coffee farming should apply with the conservation techniques through an integrated farming system, such as combining coffee plants with under-canopy crops (horticultural and food crops) economically increases farmers’ income and reduces the amount of run-off. Soil bioengineering techniques design uses vegetation for the purpose of the efforts to prevent erosion and slope instability [6]. The principles of conservation farming on sloping land include two main activities, farming, and
conservation activities, widely known as conservation farming system [7]. The policy implications for all include giving a new spirit to the plantation community to care more about conservation technology, provide incentives for every conservation action, commodity price protection and a soil organic matter enrichment program [5]. The application of a terracing system for areas with steep to very steep slopes will reduce the steepness of the slopes and minimize the magnitude of soil erosion [8] [5]. Soil bioengineering techniques design uses vegetation for the purpose of the efforts to prevent erosion and slope instability [6]. The forest degradation phase get better after rehabilitation in the last 15 years that more and more coffee cultivation, which was originally a monoculture system, has gradually changed to mixed coffee cultivation with shade trees [9]. Coffee with adequate shade trees perform agroforestry coverage that measure the soil erosion reduction in steeply sloping lands [10].

The sustainability of coffee farming achievement in the upstream watershed area is closely related to the application of soil bioengineering technology. Soil Bioengineering method is one of the soil and water conservation techniques that can be applied. This method utilizes live plants, as well as dead plant parts that are arranged in a construction with the aim of preventing soil movement. Bioengineering techniques have the advantage that they can be used for slope engineering in areas prone to landslides [6].

The response to the application of soil bioengineering innovations as land conservation technology varies at the farmer level. Farming with the application of land conservation around the sub-watershed is very important in realizing sustainable production at the agricultural household level. Then it is important to make certain that the coffee farming in surrounding forest and watersheds area conducted with adequate conservation technic, especially the soil bioengineering in good agricultural practices sustainability. This study conducted to identify the recent studies of soil bioengineering technology and its application in coffee farming toward increasing the land productivity in the upstream watershed.

2. Materials and methods

2.1. Site-research Location

Research location purposively chosen in Way Besai sub-watershed area, West Lampung District, Lampung, Indonesia. The Besai sub-watershed is part of the upstream of the Tulang Bawang watershed which downstream in the East Lampung region. It plays an important role in maintaining the sustainability and function of the Tulang Bawang watershed and a protection function for the entire watershed. Way Besai sub-watershed has about 405.846 km² located in 5 sub-districts: Sumber Jaya, Gedung Surian, Air Hitam, Kebun Tebu, and Way Tenong, as shown in figure 1.

Figure 1. Way Besai sub-watersheds site-research location in West Lampung
The Way Besai sub-watershed has four types of land cover. It was residential areas, agriculture, plantation, and forestry areas. The study area is located between -4° 55' 57” to -5° 3' 14” South Latitude and 104° 23’ 25” to 104° 29’ 57” East Longitude. The main rivers in the study area are the River/Way Besai and its tributaries consisting of Way Petai, Way Keruh, Way Besai Kecil and Way Nenas with sub-dendritic river flow patterns with different flow density patterns, between 1 - 3 km/km² and 7.5 - 20 km/km². Land-use of Way Besai sub-watersheds, West Lampung present at Table 1 and Figure 2.

| No  | Land coverage    | Area (km²) | (%)   |
|-----|------------------|------------|-------|
| 1   | Settlement/residency | 3.610      | 0.89  |
| 2   | Agriculture land | 6.750      | 1.66  |
| 3   | Plantation       | 213.450    | 52.59 |
| 4   | Forestry         | 182.036    | 44.85 |
|     | Total            | 405.846    | 100   |

Table 1. Land-use of Way Besai sub-watersheds, West Lampung [11]

Figure 2. Land cover map of the Way Besai sub-watershed

2.2. Data research collection and analysis

Studies on soil bioengineering and its role in coffee farming is carried out with the following steps and methods [11] [12]: Conducting literature studies both data, information, as well as previous research that has done from search literature in the form of journals, books and from websites. The mapping of the recent study of soil bioengineering trace using the VosViewer tool. Field studies and observations on coffee farming locations related to the application of soil bioengineering techniques. Fields study carry-out with survey method involved 167 coffee farmers as respondents. Description of soil bioengineering and related aspects and it’s the role. The data analysis method used exploration of the applicability of soil bioengineering technology at the micro-level.

3. Results and discussion

3.1. Soil bioengineering recent studies

The point of soil bioengineering technic is the use of living plant materials to perform specific engineering functions. Worldwide plant could be as soil bioengineering vegetation, include grasses,
shrubs and trees. Live plants installed in the ground by various means and in various configurations. Pioneering woody species can be used in the development of soil bioengineering systems. Woody plants should be selected. Seed and mulch used to establish vegetation on disturbed areas that would be able to regenerate on their own in drier climates [2,10]. Soil bioengineering recent studies (time duration 2014-2018) was find in 17 countries, the first cluster concentrated in Europe, USA, and China (Figure 3).

Top fives author with publication document more than 72 were Hans, Peter; Bischetti, Gian Battista; Rey, F; Tardio, Guillermo; Evette, Andre; Holanda, Franscisco Sandro Rodrigues. The organization of authors primary come from University of Natural Resources and Life Science, University of Florence, University of Milan, Grenoble Alpes University, National Research Institute for Agriculture, Food, Hongkong University of Science and Technology, University of Western Australia, and Newcastle University. The sources invoved ecologyal engineering, environmental management, plant and soil, sustainability, development in plant and soil science, springers series in geomechanics and geoengineering, engineering approach to ecosystem restoration.

The citation of key words related to soil bioengineering performed in Figure 4 (a), clustering in four called soil bioengineering, bioengineering, vegetation, dan slope stability. Figure 4 (b) describes the soil bioengineering as green infrastructure, of cource its related to vegetation biodiversity. It clearly
drives that agroforestry system in coffee farming as sustainable production were the most concern on recent studies.

3.2. Soil bioengineering trace in coffee farming

Based on the field survey, resumed that coffee farmland range dominantly (80%) (0.5-1.66 ha), 13% (1.67-2.83 ha), and 7% in 2.84-4 ha. Most of farmers have duration of coffee cultivation experience more than five years. Soil bioengineering application in coffee farming identified as five types. First type categorized as shade trees (Figure 5). This type found dominantly in Buluh Kapur, Rigis Jaya, Air Hitam sub-district. It is reasonable because coffee farming land tenure managed by community forest management called HKm. The coffee farmers obligated planting adequate stand trees as reforestation program, in range 200-400 trees. ha⁻¹.

Figure 5. Shade trees within coffee farming performed agroforestry

Shade trees are important stands in coffee cultivation, because biologically coffee plants need shade for optimal growth. Shade plants in agroforestry systems are known as MPTS (multipurpose trees species), grouped according to the yield benefits they derive. The first is forest trees that should not be cut down and the second is trees that are used as a result, they are fruit and spice trees. Coffee agroforestry is the coffee plantation system plant with adequate multi shade trees. Coffee agroforestry is categorized as simple agroforestry and complex agroforestry. Complex coffee agroforestry performed when shade trees consist of more than five types of trees and has high-canopy shade trees[13].

Various annual fruit tree species plant within coffee farm, such as durian (Durio zibethinus), petai (Parkia speciosa), jengkol (Archidendron pauciflorum), battle nut (Areca catechu), candlenut (Aleurites moluccana) avocado (Persea americana), and jackfruit (Artocarpus heterophyllus). Coffee agroforestry performance determined by the number of trees planted with coffee trees. Based on the previous worked in Tanggamus, coffee-based complex agroforestry was a primary type of coffee agroforestry system. In average, the coffee plant density was 1,719 trees. ha⁻¹ plants with MPT 182 trees. ha⁻¹. The MPT within coffee farming attain to 10.5%, and raised more than five types of shade plants [14]. In the study site, also found that an effort in replanting coffee also side by side with new planting MPT as shade trees. New planting shade trees within the young coffee plant (Figure 6)
The second effort in applying the soil bioengineering in coffee farm identified as grass strip planting. Grass strip planting in coffee farm mostly found in upstream of Cengkaan River, which is a tributary of the Campang River, is located in Pekon Karang Agung, Way Tenong District, West Lampung Regency (Figure 7).

Vegetation prevent washing away of soil particles during run off. Fast growing vegetations with deep root penetration system and vegetations that can live in a variety of soil types as well as their root system which able to bind the soil are preferred in the application of soil bioengineering [11]. Soil bioengineered systems are often able to provide a significantly more durable facing treatment, not only protecting the outward surface but improving the internal stability of the system. Additionally, the root systems bind the reinforcements together [2].

Especially in the study area in Pekon Karang Agung, Way Tenong District, West Lampung Regency, during the one-year observation period from January to December 2020, the evaluation results showed that there was a tendency to decrease the rate of sediment flowing in the Way Cengkaan River. This condition is one result of the implementation of the conservation program in the study area carried out by PT. PLN Persero Regional Lampung in cooperation with the community. River Care Program IV, which was launched by PT. PLN Persero Regional Lampung has a positive impact on improving the quality of watersheds, River Care Program by PLN, firstly launced in 2014 in Pekon Batu Kapur, Rigis Jaya, Air Hitam sub-district. Focus on strengthening of the water embankment in the Buluh Kapur tributary. A combination of mechanical methods of making embankments, waterways with bamboo as riverbank protection plants (Figure 8).
The third of soil bioengineering that applied in coffee farm found mulch form local manure sources (Figure 9). Most coffee farmers have goats or cows as livestock. The integration of coffee plants and livestock is widely applied by coffee farmers in West Lampung, including in the site research location. Awareness to use livestock waste on agricultural land continues to be fostered and developed by coffee farmers. In addition to producing agricultural waste, which is important in improving land quality, animal husbandry is one of the sources of household income along with farming outside coffee.

As part of conservation technology, applying the cover crops as green manure in soil bioengineering should optimize. Ground cover crops are generally creeping legumes planted between annual plants, alternately with annual crops or annual plants and as pioneer plants for rehabilitation of critical lands. The function of cover crops is to cover the soil from direct rainwater, rehabilitation of critical land, maintaining soil fertility, and providing organic matter. 2) Forage mulch can come from forage from hedge trimmings, grass strip plants, and plant residues[7] [16]. Root fibers could form natural mesh that could binding the soil so it is not easily carried away by the flow of surface run off [11].
3.3. Soil bioengineering and land productivity

The value of land productivity is calculated by taking into account the total income of farmers from land use for farming for one year (equivalent to coffee kg ha\(^{-1}\)). The productivity of land for coffee farming with agroforestry in previous studies in Tanggamus showed that it was able to achieve an annual income equivalent to coffee 2,553 kg/ha/year for farmers with private land ownership and coffee yield 1,390 kg/ha/year for HKMs’ farmers [17,18]. The choice of farmers in choosing the type of agroforestry is influenced by total income, land area, gender, and conservation practices, as well as experience, land productivity, and land management rights. These factors are important considerations in determining the choice of agroforestry types in coffee farming in the upstream watershed. Shade trees choice as soil bioengineering type present as land productivity enhancement form. It is improved in maintaining the land structure, quality, and productivity [19]. Land management that does not pay attention to soil and water conservation will result in less productive land whose condition will continue to decline until it reaches a critical level. Erosion and critical land are not local problems but are problems that concern the watershed as a whole [20]. Rehabilitation and conservation efforts, through agroforestry that involving community participation and empowerment is expected to overcome damage to critical sub-watersheds, restore land productivity, restore natural sustainability, and improve the socio-economic community [21].

Production and productivity are also in increasing trend and made positive impact on socio-economic status of the beneficiaries in terms of increase in additional employment and additional income generation. The awareness built among the beneficiaries about importance of natural resources, watershed development programs, advanced soil and water conservation technologies and production technologies for enhancing productivity [22]. The conservation farming system for bench terraces and mound terraces can increase farm productivity and farmers' income, and can reduce the rate of erosion[23].

Building positive farmers' perception toward soil bioengineering technique important to linked with land productivity improvement. Farmers perception correlated with relative benefit, suitability, simplicity, trialability/testability, and observability/observability [24]. Participatory and collaborative planning need to carried out during the preparation of appropriate types of conservation activities and the contribution of resources from the community in order to integrate and sustain micro watershed management activities [25].

Farming activities other than coffee also show improvements in land productivity, labor absorption, and the agricultural sector growth. The more productive the allocation of labor’s farmers and the more business activities in the agricultural sector will improve the condition of the structure and distribution of farmers' income as land productivities indicator. Activities in the agricultural and non-agricultural sectors can alleviate the unequal distribution of household income of farmers.

4. Conclusions

The recent studies (2012-2020) of soil bioengineering primary based on key words citation triggering in cluster called soil bioengineering, bioengineering, vegetation, dan slope stability. Soil bioengineering as green infrastructure connected with vegetation biodiversity. The agroforestry and in coffee farming system clearly noted as evidence of sustainable production in recent studies. Soil bioengineering application in coffee farming found was shade trees as MPT in agroforestry system, bamboo and others specific plants as restored plant in river streambank, and mulch from manure and cover crop. Soil bioengineering within coffee farming ultimately provide land productivity enhancement through production increase and become an enrichment source of income for coffee farming households.
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