The importance of soil biodiversity for sustaining the development of sisal in Sumbawa and Sumba with special reference to soil-borne pathogens

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Abstract. Sisal (Agave sisalana) is a good source of natural fiber for various purposes, e.g. handicrafts, doormats, boat ropes, wrappers, pulp, carpets, geotextiles, etc. Sisal is now being developed in some part of Sumbawa and Sumba islands due to its ability to grow at drought conditions and arid-semiarid regions. Most of the areas were originally grassland with shrub spots that have never been disturbed. Intensive planting Sisal under monoculture system for long period could alter the balance of soil biodiversity which lead to an emergence of a disease(s), particularly soil borne diseases. Recently, there are two distinct diseases (bole rot and zebra diseases) occurred in the areas indicating that soil health is under stress. Successful sisal sustainable development in these areas needs good agricultural practices with special attention to the management of biodiversity. Since soil biodiversity has an important role in stabilizing stress and disturbance. This paper discusses how to sustain Sisal development in Sumbawa and Sumba, including: good management sisal residues, intercropping, and environmentally friendly pest and disease control.

1. Introduction

Virgin soil is habitat for an enormous species of microorganisms (bacteria, actinomycetes, fungi), small fauna (nematodes, worms, insects, mites), and other organisms. They interact each other forming an equilibrium diversity and contribute to several cycles, such as carbon, nitrogen, and other nutritional cycles, soil detoxification and reclamation, and microclimate control, which are important for the health of environment [1]. Converting the natural ecosystem to agricultural system, could alter the balance of biotic interactions because of habitat modification during the shift of ecological process by human activities [2]. The monoculture system in modern agriculture led to reduce biodiversity [3] and its level in the agricultural systems depend on the number diversity of vegetation and fauna. When in a site has limited number of species and the biodiversity is threatened, this ecosystem will imbalance [4] and could trigger the explosion of pests and diseases.

Natural biodiversity is important factors for continuity of ecosystem production including food and medicine, water, shelter, and other natural resources (genes, species). Biodiversity also
has an important role in absorbing pollution and climate stability [5]. Many forest and idle lands have been opened to fulfill the increase of basic need (food, clothing, and dwelling) due to the continuous increase of human population. As an example, Indonesia has 12.4 million ha of idle land outside Java [6] and could be possibly cultivated to fulfill the demand. Sumbawa and Sumba islands are part of the Nusa Tenggara region which has 4.9 million ha of dry climate upland areas with annual rainfall less than 2,000 mm, 5-10 dry months [7]. These conditions are usually classified as arid-semi arid lands. The soils are generally low in microbiological activities and poor in natural fertility, shallow and sometimes contain rock fragments [8], hence most of these soils have not been intensively used for agriculture. Only few crops could adapt to this dry climate and semi-arid lands, one of them is Sisal (Agave sisalana). Intensively cultivated this new crop could disturb the equilibrium of the in-situ soil microorganisms. The exudates secreted from agave root favor certain soil microorganisms possibly plant pathogens. On the other hand, those exudate substances could suppress beneficial microorganisms. Furthermore, inappropriate management of agricultural practice could worsen the situation.

Successful sisal sustainable development in these areas needs good agricultural practices with special attention to the management of biodiversity. This paper discusses steps how to successfully development Sisal in Sumbawa and Sumba, including: good management sisal residues, intercropping, and environmentally friendly pest and disease control.

2. Why sisal

Sisal is a succulent, xerophytic tropical plant with thick cuticle and waxy leaf coating. The plant uses a special photosynthesis pathway called Crassulacean Acid Metabolism (CAM) pathway, where stomata open at night to collect CO₂ but close during daytime to minimize transpiration. The CO₂ is deposited in vacuoles as malic acid and will be retransformed to CO₂ during photosynthesize process at the day [9]. According to [10] CAM pathway efficiently used water without reducing crop yields particularly in drought conditions. Sisal is also able to absorb more CO₂ than its production. Therefore, the plant survives well at drought conditions and arid-semiarid regions.

Sisal is one source of natural fiber for household purposes such as handicrafts, doormats, brooms, interior materials, boat ropes, wrappers, household crafts, pulp, a mixture of carpets, sacks, geotextiles, brush polishing machines, fishnet materials, etc. [11]. World sisal fiber consumption of 300,000-400,000 tons/year [12] has not been fulfilled yet. Hence, the development of Sisal in the regions could potentially increases local income. Besides its fiber, sisal wastes from decortication process can be further processed for bioenergy, animal feed, fertilizer, and pharmaceutical purposes [13]

2.1. Agroecological requirements for sisal growth

Sisal grows well in hot climate and arid regions, preferably in sandy soil (well-structured and has enough porous) although the plant could adapt in most soil types except clay. However, the plant has low tolerance to high moisture and saline soil conditions. According to [14], the best soil conditions for sisal growth are free-draining non-saline soils with soil depth not less than 100 cm to support root growth [15]. So, soils must be well aerated and enough nutrient (N, P, K, Ca, and Mg). [16] added that Sisal plant grow better on limestone soil since plants with CAM pathway, have calcium levels higher than in non-CAM plants [17]. Sisal grows better when annual rainfall distributed well around the year ranged from 600 to 1500 mm with seven months rainy season [18; 15] with temperature ranged from 10-32°C. However, Sisal may still able to grow under less or erratic rainfall [19]. In general, the climatic conditions in West Sumbawa are dry to very dry which is marked by the short rainy season which runs from late November to March (3-4 months) with monthly rainfall ranged from 125-150 mm [20].

2.2. Development of Sisal in Sumba and Sumbawa
Sumba and Sumbawa are parts of West Nusa Tenggara (WNT), where the conditions are semi-arid-tropical climate. The typical climate is affected by rainy and dry season. The rainy season lasts 4 months from December to March, whilst the dry season lasts 8 months from April to November. Most of the dry lands are characterized by very low soil fertility and low organic matter content [21], poor soil aggregates, sensitive to erosion, and major nutrient content (N, P, K) relatively low [22].

Sisal plantation has been developed in Sumbawa since 2011. The development has been spread to Sumba and also small part of Lombok. At the moment sisal is cultivating in Plampang, Sumbawa in an area of 1200 hectares as a core land, but only 400 ha has been cultivated, whilst in Sumba there was an area of 6000 hectares available for sisal development. Most of the sisal plantations in Sumbawa and Sumba were converted from shrubs and grasses ecosystems. Changing vegetation to estate crops and continuous land intensification would change microclimate and cause degradation of soil fertility and could resulting in changes in microbial composition and activity in the soil. Altering ecology because of the shift of land cover and use by human activities would affect biodiversity and their interaction [2]. In Tanzania, continuous growing sisal in the same areas for a long period of time made the soil depleted its nutrient reserves rapidly. Nitrogen, potassium, calcium, and organic matter levels in the soils were much lower compared to virgin soils nearby. The pH values of the soils also decreased to 5, whilst the optimum pH for sisal growth is 6-7 [14].

Sisal grows well on well-structured and adequately porous soils with arid-semi arid climates [14]. Sumbawa and Sumba are also categorized as arid-semi arid ecological lands. However, in some areas, the soils have poor drainage, the water stay on the soil surface due to the soil has bad porosity. These conditions favor some plant pathogens, such as Phytophthora nicotianae and Aspergillus niger, the two dominant pathogens found infected Sisal. There are three symptoms appear when P. nicotianae infects the plant, i.e.: (1) Zebra Leaf Spot; (2) Bole Rot and (3) Spike Rot [23]. Zebra Leaf Spot occurs when the leaf is attacked. The first symptom appears as a small pale green patch and then the patch develops as purplish circular spot. The lesion will form dark purple and pale green concentric rings and will becoming dark grey and yellowish white lesion, as zebra streak. The lesion sometimes produces sticky dark exudate. This first symptom of bole rot is the leaves slightly curled and cannot open wide, and then the leaf blade withers starting from the bottom. If the bole is splitted, it will appear that the infected part turns brown sometimes accompanied by a reddish color while the healthy part remains white. This symptom often has similarities with the symptom caused by the infection of A. niger. Spike Rot occurs when the tip of the spike rot due to the bottom part of the bole decay and develops upward. Leaves are usually slightly curled and slightly purplish blue. At this stage, the diseased plant is easily uprooted. A. niger causes wet and soft bole rot resulting the leaves downfall and yellow. The infected bole becomes yellowish brown with pinkish margin. When the bole is damaged, infection of the fungus causes basal dry rot [19].

3. Sustainable Management for Agave Development

The success of Agave development not only come from the best variety and healthy plant seed materials used, but also the supporting soil should be healthy. As [24] stated, soil biodiversity is the main factor for sustaining the ecosystem function and indicator of healthy soil. Soil health can be achieved by proper soil management to get its optimum productivity and low occurrence of plant disease. According to [24a], interaction among soil microbial diversity, crop, soil type and management could protect plant from soil-borne pathogens infection.

Although the marginal semi-arid lands in Sumba and Sumbawa are suitable for Sisal, soil fertility is the main restraining factor to sustain sisal production. Generally, soil conditions in arid and semi-arid regions is indicated by low fertility and low water availability. The low fertility means the soils are shallow with some patches of stones. The soils also have low content of organic matter, low nitrogen and phosphorus availability, low water-holding capacity, but have high pH [25]. Sisal required high calcium to produce high quality fiber, hence continuous grow
sisal on the same soil year after year could deplete soil nutrient reserves, particularly calcium. Therefore, the soils in those areas will need high nutrient inputs to sustain agricultural production and to support the stabilization of the biological processes including nutrient cycles and other microbial activities. However, addition of fertilizers from external sources will be costly. Another alternative source of fertilizers is incorporation of compost from sisal wastes from decortication process to increase fertility. Soils rich in organic matter consider as fertile and healthy soil [26]

3.1. Addition of organic matter

The waste products from decorticated process are about 96% of fresh leaves. They are rich of chlorophyll, pulp and short fiber [27]. During the composting process, several compounds are produced and have functions as natural bio stimulants and inhibit the development of soil-borne pathogens [28]. Compost also provided nutrients for microbial antagonists to proliferate and enhanced their capability against soilborne pathogens [29] for example Trichoderma asperllum increased its potency against P. nicotianae on pepper when [30].

Currently, vermicompost, composted organic wastes processed by earthworms, is popular since it has several advantages. It improves the soil texture, aeration and water holding capacity of the soil. These conditions support root growth and development of good microbial population, including nitrogen fixers, phosphate solubilizers, etc. Therefore, it could control soil erosion and at the same time it provides nutrients to the plants as well [31]. Furthermore, the enzymatic activities in the earthworm gut, control toxic metal, which eventually reduce metal toxicity in the soil [32]. The decomposition of sisal pulp using earthworm Eisenia fetida took only 60 days to produce compost with high Nitrogen, Phosphorus and Potassium content. The compost also had high microbial activities. The earthworm population also increased 10-15 times so that it can be used for subsequent waste composting process [33]. Other benefits of vermicompost are: it increased microbial populations in which some of them produced plant growth hormones and enzymes; acted as biological control agents for plant pathogens [34], such as actinomycetes [35]. Vermicompost was also rich in chitinolytic and anti-fungal bacteria that could acted as soil suppressant [36] since some of them, i.e. Bacillus subtilis produced volatile compounds which were able to inhibit the growth of the pathogenic fungus such as Botrytis cenerea in vitro [37].

Thus, the most appropriate sisal waste management is using it as compost through vermicompost process since it is relatively faster than regular compost. The compost could be used as source of organic matter to improve soil properties, including soil conditioner and soil suppressant as well.

3.2. Intercropping System

Sisal is usually planted in double rows and has a 3.8 m harvest space for other crops to grow. Another alternative method to support the sustainability of Sisal development is intercropping system using the harvesting space. Intercropping system has several benefits, i.e.: increase biodiversity (fauna, flora, and also microbes). Increase plant diversity in the same area attracts some beneficial insects, such as pollination insects, predators, and parasitoids of insect pests. Different plant species had different cluster of microbial communities since different plant rhizospheres produced different compounds of root exudate, which be favored by certain microbes. The microbial growth, particularly pseudomonad also multiplied significantly in the rhizosphere [38]. [39] stated that composition of soil microbial communities and diversity played important roles in maintaining soil health and productivity. Furthermore, intercropping system enhanced microbial biodiversity, including fungal and bacterial diversity [40]. [20] suggested to intercrop sisal with peanuts, mung bean, sesame or upland rice since these crops have different
growth rate and height, hence they do not compete sun rays, water, nutrient and space with Sisal. Planting several types of crop between Sisal row or in harvesting space could control weeds.

Planting cover crop after harvesting period could control weed and improve soil fertility. Sun hemp (Crotalaria juncea) can be grown after harvesting for 30 days between row, and then incorporate the biomass to the soil to improve soil fertility and microbial activities [20]. C. juncea gave high organic matter value, enhanced production mycorrhizal spores, and specific micronutrients for plant growth [41]. The presence of mycorrhizal diversity plays a role on nutrient uptake and efficiency use of water [24]. Mycorrhiza could support plant up take P up to 90 % of requirement [42]. Mycorrhiza also enhances plants’ tolerance to adverse environmental stresses and induces resistance against soil-borne pathogens [43]. Inoculation C. juncea with Acaulospora sp., an arbuscular mycorrhizal fungus, protected the plant from arsenic toxicity, indicating that mycorrhiza could act as phytoremediation in Arsenic-contaminated soils [44]

4. Conclusion

Sisal development in Sumbawa and Sumba islands could alter the origin soil biodiversity and the composition. Continuous planting Sisal in the same areas could decline certain soil microorganisms, and on the other hand other communities could dominate the soil microecosystem and could probably trigger some diseases, such as zebra disease caused by Phytophthora nicotianae and bole rot caused by Aspergillus niger. When soil biodiversity is in equilibrium state, then the ecosystem will in good function. Therefore, to sustain the development of Sisal and balancing the soil biodiversity to maintain soil health and productivity, several attempts could be done, such as: (1) adding sisal waste in form of vermicompost and (2) applying intercropping system. Intercropping system is better than than monoculture since the system support micro-meso flora and fauna, and microbial diversity both in aerial and soil sites. These conditions will improve microbial composition and soil fertility as well.

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