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A Review of Challenge and Prospect of No-Tillage Practice to Sustain Spices Cropping Systems in North Maluku

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ABSTRACT

No-tillage or zero-tillage has been adopted for years by local farmers to sustain islands-based tropical spices cropping systems across the North Maluku region. Various studies in other parts of the world have proven a remarkable effect of this practice on soil health indicated by the enhancement of soil aggregate stability and increased water infiltration. No-tillage practice, however, with the removal of plant residue might cause an increase in soil compaction. In addition, the status of soil health is not only determined by soil management factors but is also influenced by climatic factors. In tropical region, high rainfall and season fluctuation in climate may deteriorate soil health as a result of the formation of soil compaction in no-tillage soils. Soil compaction occurs due to the rapid decomposition rate of soil organic matter triggered by wetting and drying oscillation process. It is hypothesized that an increase in the level of soil compaction may potentially disturb soil health indicated by the decline in natural capacity of a soil to suppress soil-borne disease. This paper, therefore, explores how a no-tillage practice can induce soil compaction. It will also describe the mechanism of the effects of soil compaction on the reduction in soil capacity to naturally suppress soil-borne disease, which might be able to influence the sustainability of small islands-based tropical agricultural systems in North Maluku.

Keywords: *islands-based tropical spices cropping systems, natural disease suppression, no-tillage, soil compaction*

I. INTRODUCTION

The rising concern for spices crop yields decline across North Maluku region, Indonesia should probably be associated with the adoption of soil management practice on agricultural lands. It is noted that no-tillage is the most common technique used by local farmers in developing their agricultural farming system in small islands. The technique is practiced mainly for cultivating such spices crops as nutmeg and clove on sloping-lands. Unfortunately, it is found that conservation tillage system used in small islands-based agricultural systems in the region merely depends on no-tillage practice while removing crop residue from the soil surface. This can trigger the formation of soil compaction and hence the limitation of root growth and the reduction of crop yields.

No-tillage refers to a form of conservation tillage practice that is cultivating land for sowing crops with little or no mechanical disturbance on the soil surface [1]. This soil management technique has been widely adopted in many parts of the world including the United State and Brazil [1, 2], China [3]; India [4, 5], Pakistan [6], Bangladesh [7] and Indonesia [8, 9]. These reports indicate that the technique is compatible to be applied in both cultivation of annual and perennial crops, and hence is continuously being advocated for many production systems world-wide as an appropriate management option for enhancing soil health.

Various studies in other parts of the world have revealed that application of no-tillage technique in agricultural soils may sustain soil health through the improvement of soil physical, chemical and biological properties [2, 10, 11, 12, 13]. Silburn et al [13] noted that no-tillage practice with greater cover of crop residue retention on the soil surface has a significant reduction in soil erosion and increased soil water storage. Further, Six et al [2] concluded that soil carbon (C) levels increased in between 200 and 440 kg C ha^{-1} yr^{-1} in soil under zero-tillage system, and hence reduces greenhouse gas emission. Additionally, other previous studies have suggested that an increase in soil organic matter in agricultural system that includes no-tillage and crop residue retention can favor the development of soil microfloral activity and diversity [14, 15].

The above research reports confirm that to obtain the benefits of practicing agriculture into such a way of conservation tillage it needs to include both reduced- or no-tillage operation and crop residue retention. The practice adopted in small islands across North Maluku is potentially contradict to the notion of conservation agriculture that minimize soil disturbance and retains more than 30% crop residue on the soil surface [1]. Crop residue removal is considered the cause of soil nutrient depletion as well as through the reduction of soil organic matter (SOM) accumulation that induces soil compaction [2, 10, 15]. Ishak and Brown [16] suggested that an increase in the level of soil compaction may potentially reduce the capacity of a soil to suppress soil-borne disease, and in turn may result in a decline of crop yields.

Despite being commonly used as the main option in small islands-based cropping systems in North Maluku, no-tillage practices and crop residue removal, as well as its potential effects on the formation of soil compaction, has received less attention. This paper, therefore, explores how a no-tillage practice can induce soil compaction. Additionally, the effect of soil compaction on natural disease suppression as well as their effects on the sustainability of small islands-based tropical agricultural systems in North Maluku will also be described.

1. *The Formation Of Soil Compaction Induced By No-Tillage Practice As A Challenge To Small Islands-Based Agricultural System In North Maluku*

North Maluku, Indonesia, consists of small islands in which less than 70 islands are inhabited [17]. The topography of the islands is mostly characterized by sloping lands. Thus, agricultural farming systems developed by local farmers are associated with the topographical condition of the land. This is indicated by the selection of perennial spices crop commodities including nutmeg and clove to be the main crops cultivated in the region and no-tillage system as the basis for soil management practice.

The adoption of zero-tillage operation in tropical regions including Indonesia environment can, however, have detrimental effects on soil health. It is noted that a continues practice of zero-tillage on agricultural lands might provoked the formation of soil compaction, which is influenced by climatic factors {18}. Referring to the definition proposed by the Ad Hoc Committee of Soil Science Society of America, soil compaction is considered a decline of soil structure whereby 'soil particles are reordered to lessen void space and bring them into closer contact with one another, thereby enhancing the bulk density' [19]. Soil compaction is mainly induced by hotter temperature and higher rainfall throughout the year. Such climatic condition can trigger sequential drying-wetting cycles in the soil, and thus disrupt the physical characteristics of a soil [2, 20, 21].

How can climatic factors trigger the formation of soil compaction in tropical agricultural lands adopting no-tillage system? There are two approaches that can be used to answer the question.. Firstly, this is associated with a cycle of drying and wetting that happens consecutively and hotter temperatures experienced in tropical regions may likely speed up the decomposition rate of soil organic matter and the alteration of soil carbon in the topsoil layer [2. 20, 21]. It is reported that hotter temperature in the tropics can promote the rate of soil carbon turnover twice as rapid in tropical soils compared to temperate soils [22, 23]. Secondly, the adoption of no-tillage system in tropical farming systems is not followed by crop residue retention. The removal of crop residue from the planting areas may reduce the availability of sol organic matter and therefore can induce compaction.

Our snap shot study in several small islands in North Maluku (Ternate, Tidore, Makian) has found that the region is an important spicy production center, with cropping predominantly growing well on the volcanic Inceptisol soils of the region [24]. These soils are dominated by a sand fraction and containing low SOM, so as are prone to soil structure decline [25].

Soil structural decline in associated with compaction and low SOM content has a deleterious effect on soil and plant health [21,25]. Previous studies revealed that the destruction of soil physical health occurred due to increased compaction, which was indicated by increased soil bulk density and soil strength and low soil total porosity [21, 26, 27]. Such a soil condition may hamper both the penetration of plant root and nutrient uptake by plant roots and as a result can cause yield decline [26, 27]. In addition, the impairment of soil health due to soil structural decline was caused by the reduction of soil microbial diversity and activity. This can eventually damage soil biological functions particularly in related to the prevention of soil-borne disease transmission [21]. Thus, soil compaction can potentially be the challenge to sustain high production of spices cropping systems in the region.

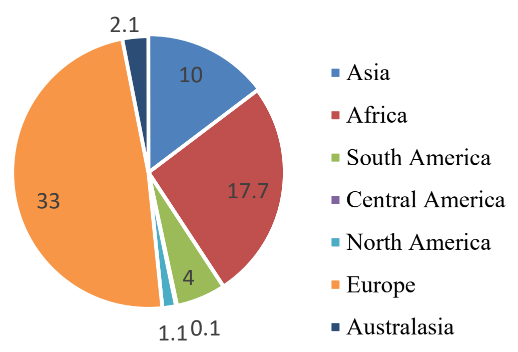

Figure 1. Compaction induced-degraded areas in the world in million ha (adapted from Oldeman [28]).

Soil structural decline due to compaction occurred through out the world has been recorded by Oldeman [28]. From the total 68 million ha degraded area, the largest degraded area is found in Europe (33 million ha); followed by Africa 17.7 million ha and Asia 10 million ha. Degraded lands also occur in other regions like South America (4 million ha); Australasia (2.1 million ha); North America (1.1 million ha); and Central America (0.1 million ha) (Figure 1). It is noted that soil compaction problem is the main issue in Europe that is categorized as temperate region. The formation of compaction in this region is mainly induced by intensive use of heavy machinery [29]. Although the data were published more than 30 years ago and there are no new statistics available, it is expected that land degradation generated from compaction could be higher or lower due to changes in soil management practices [21].

2. *Soil Compaction as the Main Factor Affecting Natural Disease Suppression*

The soil-born disease is the major production constraint threatening the sustainability of agricultural systems worldwide [30]. The outbreaks of soil-born disease are noticeably more frequent in tropical environment. Ishak et al [30] have reviewed that the onset of soil-born disease in the tropics is the output of climatic and soil management factors interaction. Hotter temperature and higher rainfall in the tropics are the climatic factors that facilitate short generation times and greater viability of soil pathogens, whereas soil management factors in association with the climate of the region lead to soil structural decline and a further build-up of pathogens [31, 32]. Such a condition also occurs in nutmeg cropping system that includes no-tillage practice, whereby the crops are often attacked by white root disease in association with Nutmeg stem borer attack. The attack can cause an adverse effect on the nutmeg yield.

Every soil in the tropics can, however, potentially deliver a capacity to naturally suppress soil-borne disease. Natural disease suppression is defined as a natural level of capacity of a soil to control an incidence of disease [30, 33], indicated by only very low level of disease occurs at the farm scale even when the disease pathogens are present in the soil and host plants are susceptible to disease [21, 33]. A theory of plant pathology explains that the key factors determining the establishment soil-borne disease are the concurrent interaction between pathogen activity, existence of susceptible plants and favorable environmental conditions [34 ,35] (Figure 2). The key factors as well as their interactions must be the focus on the further study on disease suppression.

The formation of compaction in agricultural soils is recognized as the main soil physical factor contributing to the decline of a soil capacity to suppress soil-borne plant disease. The mechanism can be described from the contribution of compaction to the destruction in soil physical integrity [36]. Increased compaction can significantly reduce total porosity and change the distribution of soil pore and pore continuity, which in turn can impede permeability of water and air leading to the reduction of soil oxygen diffusion [37, 38]. In addition, high soil moisture content in compacted soils can disrupt aeration [39] and therefore promote an anaerobic condition in the soil environment. Such a condition has initiated the change of soil microbial communities and the reduction of microbial activity.

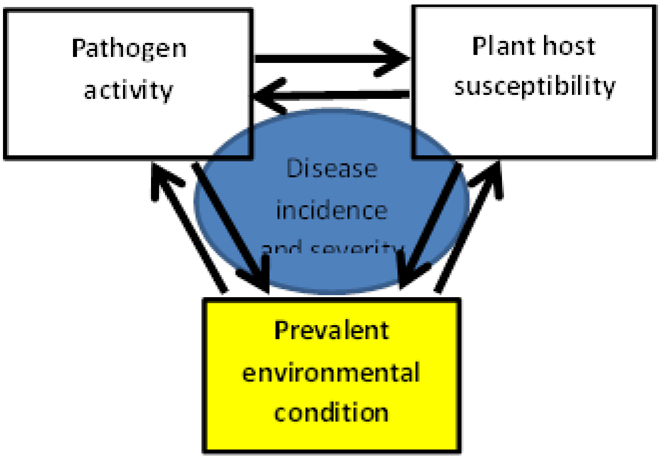

Figure 2. Disease incidence and severity in agricultural farming systems induced by the three factors (adapted from Agrios [34])

Changes in soil microbial communities were considered a factor that could stimulate disease development in compacted soils. A previous study using Capsicum plant as a model found that the number of diseased plants in compacted soils inoculated with pathogen inoculum was higher than in less compacted, disease-inoculated soil [21]. The study revealed that roots from nearly 50% of young plants in compacted soil were attacked by disease over a period of 10 days after planting. This confirms that the 10-day period after planting is the critical time period for the disease onset. The compacted soil inducing highest disease levels has low soil microbial biomass, size, activity and diversity. Overall, the effects of compaction on the impairment of natural disease suppression of a soil can be identified through changes in the composition and activity of soil microbial community.

3. *Managing Soil Compaction To Sustain Agricultural System Under No-Tillage Operation*

Evidence has shown that heavy compaction has ability to induce significant changes in the composition and size of soil microbial community [21]. Thus, soil compaction can be considered having further effect on the natural capacity of soil to suppress plant soil-borne disease infection. Our previous study illustrated the mechanism of the potential impact of soil compaction on the impairment of natural disease suppression of soil. From a field, trial observation on Capsicum growing soils, it is noted that the number of capsicum plants displaying a symptom of soil-borne disease was significantly higher in conventional farming systems compared to the plants grown in the no-tillage farming systems [21]. The study confirms that the decrease in natural disease suppression in the conventional-tilled soil was closely related to lower diversity and size of soil microbial community as a consequence of the low content of organic carbon in the soil.

A similar finding from a pot trial also showed that compacted soils had a relatively poor capacity to suppress disease [21]. Disease onset was found in ‘infected’ and inoculated soils at all levels of compaction tested, but the disease severity was greatest in heavily compacted soils. Microbial biomass and bacterial community size were found low in heavily compacted treatments, whilst fungal community size tended to increase. The decline in natural disease suppression of a soil was also presumably associated with the low content of carbon and calcium in the soil. Organic matter and gypsum amendment into the soil can help increase the capacity of soil to naturally suppress disease. Soils with high of organic matter addition (4%) and soil moisture content at field capacity tended to have high natural disease suppression, respectively. In addition, supplying water irrigation to keep soil water content between 80 and 100% of field capacity can boost soil microbial activity and enhance the level of natural disease suppression of the soil.

The extent of soil compaction to the heaviest level (1.6 $g.cm^{-3}$) significantly alleviated natural disease suppression of the soil [21]. This was indicated by the higher number of plants infected by disease in the heavy compacted treatments. Also, the growth and distribution of roots were significantly inhibited by heavy compaction, which probably interfered nutrient uptake into the roots. This eventually lowered plant vigor and increased the susceptibility of plants to disease attack. Thus, the mechanism of compaction affecting the dynamics of soil microbial community is considered an important part of the explanation for disease suppression in soils.

II. CONCLUSION

It was clear from our previous study that soil compaction can potentially occur in spices cropping systems adopting no-tillage operation. Soil compaction potentially has a detrimental effect on the capacity of natural disease suppression of a soil. Yet, some tropical soils have displayed their capacity to suppress soil-borne disease, which can be established through conservation tillage including no-tillage along with crop residue retention as it creates an extremely competitive environment with possible competition between microbial communities.

Our previous study had elucidated the relationship between soil compaction and natural disease suppression on vegetable farming systems. Using the pattern of the relationship on the vegetable farming systems, it is suggested to do further, relevant research on spices cropping systems to gain better understanding of the occurrence of complex interactions between components of soil factor and soil microbial factor, as well as the relative scale of the effects of these factors on the susceptibility of spices crops to the infection capacity of disease and pathogen.

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