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Mini Review: Intensification of Mulching to Improve Soil Moisture in Vanilla Plantation

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ABSTRACT

Continuous water uptake from soil via the root system and it transport into the leaves system is a basic mechanism in plants to maintain growth and reproduction. Consequently, sustaining soil moisture to keep water supply into the plants should continuously occurred to maintain growth. Under condition of global warming scenario and robust agricultural practices, soil organic carbon which plays as a key for soil moisture and fertility are continuously diminished. This condition could subsequently endanger the growth of shallow rooted plants, such as vanilla. To mitigate the impact of global warming and robust agricultural practices, enhancing carbon sequestration to inhibit water loss is regarded crucial. However, although mulch materials are locally available in most land crop plantations, those materials are rarely viewed as functional for maintaining soil moisture. Both water stress and mulching might have not been seriously anticipated in conventional agricultural practices. For example, continuous decreased in yield of vanilla plants are usually handled by applying pesticide or fertilizer, without addition of mulch. The objective of this review was to gain a better understanding of soil moisture to increase vanilla growth and reproduction. This review found that mulching could reduce evaporation, increase soil organic carbon and soil fertility. It is concluded that intensification of mulching could enhance sustainability of vanilla plantations.

1. Introduction

Assimilation of CO_2 into sugar takes place mostly in the leaves (Taiz and Zeiger 2002). This process requires continuous supply of water from the root to generate ATP and NADPH. Waters taken up via the roots are also required by plants for stomata opening which enable the uptake of atmospheric CO_2 (Jackson *et al*. 2000). Therefore, in order to maintain CO_2 assimilation in the leaves which requires aqueous medium (Kirschbaum 2004), sustaining water uptake from soil via the root is becoming very crucial. According to Chaves (1991), carbon assimilation may diminish to zero when relative water content down to 70%. This indicates that carbon assimilation in leaves very sensitive to water uptake in the roots. However, soil where water is taken up might have undergoing various changes particularly in its capacity to hold water because of factors such as global warming and soil management (Stergiadi et al. 2016). So, to sustain carbon assimilation in the leaves, the capacity of soil to hold water has to be maintained. Maintaining soil moisture can be employed by minimizing water evaporation from soil surface. Since evaporation involving the breaking up of hydrogen bond which is speeded up by increasing temperature (Taiz and Zieger 2002, Solomon 2011), inhibiting water evaporation should involves maintaining soil temperature in a range that do not induce the breaking up of hydrogen bond.

By addition of organic material for mulches, light from the sun can be intercepted and temperature can be maintained in a relatively acceptable level. Manu et al. (2017) have examined the effect of various vegetative mulching materials on various crops. They concluded that improvement of yield shown by those crops attributed by lowering soil temperature and increasing soil moisture. In other reports, the organic mulch was described as become an important source for mineral required by plants to grow (Kumar et al. 2014). More importantly, addition of organic mulches could also enrich the soil with organic carbon which enhances the capacity of soil to hold rain water (Bai et al.

2013). So, to mitigate the impact of global warming on crop production, intensification of mulching could become an important alternative. Furthermore, since material for mulching is locally available in plantations, small holder farmer could easily apply mulches into their crop plants.

Under farming practices where vanilla plants were grown by conversion of forest or coffee plantation, productions of yield were found excellent in ca 3-4 harvest. In the ensuing period, yields were then continuously decreased. This kind of production has long been experienced by small holder farmer. Therefore, data on vanilla production published by *Badan Pusat Statistik* (BPS Bali) also showing similar pattern (Fig. 1). According to this data, vanilla production was slowly increased to a highest level and stay in this level for a very short period before decreasing to a very low level. Production were then not increased for more than 5 years.

Similar pattern was also found for cacao, which was grown in land after clearing off coffee trees. In the initial harvest, yield was found excellent but then continuously decreased. Since these crops greatly support income for small holder farmer, various efforts certainly have been made to improve yields. However, yields of these crops were not found improving. It is speculated that important factors have not been considered during the practices which eventually make those crop yields not sustainable.

2. Agricultural practices could deteriorate soil organic carbon that originated from natural mulching

Small holder farmer in Bali used to develop vanilla plantation by planting cutting vine in mixed culture with legumes. Newly growing vines were trained in such a way to make hand-pollination easier to perform. Nutrient were usually added whether by application of fertilizer via the leaves system or root system. Soil moisture and soil organic component has been known to have an important role for optimal growth of vanilla, therefore it was recommended to water vanilla plantation during dry season and to add manure (Rismunandar 1989). This watering is particularly important since vanilla plants has 2 kind of root i.e. aerial root and terrestrial roots which easily exposed by water stress. Both aerial and terrestrial root are originated from node. Whereas aerial root originated from vines in the atmosphere, terrestrial root originated from vine in the soils. Aerial root can grow down into soil and become terrestrial root. This terrestrial root always branched and grow horizontally in soil for up to 20 to 25 cm depth (Reddekoff 2009). In my own observation, terrestrial roots are also grow and branched horizontally on the soil surface. Without addition of mulch, this surface root could be easily exposed to water stress. However, although this vanilla produced shallow root system, application of organic mulch is rarely found in Vanilla plantation.

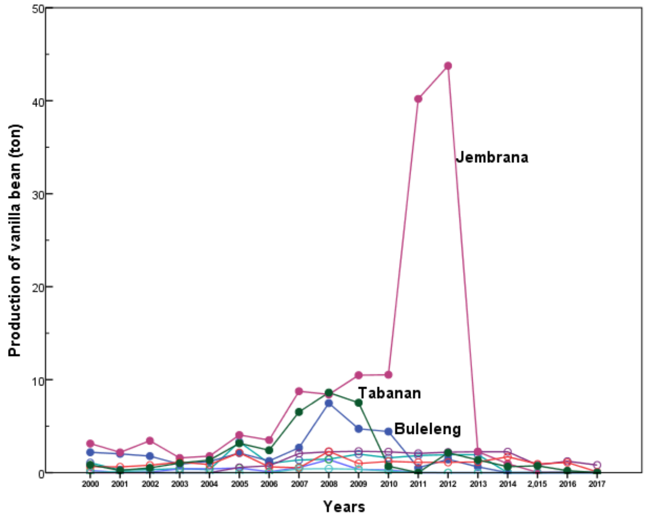

Figure 1. Vanilla production in Bali during the period of 2000 – 2017. Three highest vanilla production are shown by Jembrana, Tabanan and Buleleng regencies. After attaining optimal, vanilla production were then not found increased into similar peak for 4 to 7 years (Data were collected from BPS Bali).

A Mulch is defined as any materials that (a) is spread over the soil surface and (b) influences soil characteristics and sometimes plant growth (Bell et al 2009). Various mulch materials are now available for growing shallow rooted plants, such as plastic and organic carbon (Ferrara et al. 2012). However, to enhance water percolation, soil biota and nutrient cycles, organic carbon is regarded more effective than plastic (Bai et al. 2014, McMillen 2013). Various kind of organic mulches are available in a relatively huge amount. Some of those have traditionally been used for mulches material when growing shallow rooted plant. However, the other materials are very often viewed as waste only. For example, whereas rice straw, as by product of agriculture, has long been used for production of onions and garlic, materials such as dry leaves, branches and woods or grass clipping are rarely used to mulch dry land crops. Although according to Measley 2010, these materials are naturally mulches landscape and become an important component in farming sustainability.

Agroforest, as a traditional agricultural system, has a natural mechanism of mulching landscape. In tropical country, this system could naturally evolve since the heterogeneity of plants population. Plants regarded as highly valuable for better income will be cultivated and becoming important commodities. These include woody plants for building and non-woody plants for food and other uses. In this traditional agroforestry, plants are usually not added inorganic fertilizer. Nutrient for the growth of crop plants is a cycled nutrient which is originated naturally from mineralization of dry leaves or nitrogen fixing microorganism. In this system, crop yield is relatively sustainable. For example, traditional coffee plantation grown in mixed culture with legumes and other trees produces relatively constant yield for decades.

Figure 2. Vanilla plants are grown with addition of dry leaves, woods and grass clippings (Adiputra, unpublished data).

In the subsequent economic development, crop yield was produced massively to make more money. Traditional plantation then shifted into other plantation by clearing trees. With more incomes, the small holder farmer could eat more variable foods, build more comfortable houses, better clothes and the most important is a longer education for their children (Johansson & Persson 2012). Unfortunately, enhancing yield could eventually then make crop yield to burst (Clough et al. 2009) attributed by production constraint such as plant diseases and environmental pressure. The duration of optimal crop yields could have been very short in plantation that previously developed by shifting traditional vegetation or by deforestation. In this plantation, natural organic mulch materials are available in continuously less amount (Clough et al. 2009). Consequently, soil organic carbons that originated from natural organic mulches are also then continuously depleted. Therefore, sustaining yield in dry land that contains very low soil organic carbon would require a high cost. This particularly because most nutrient and water required by the crop plant must be deliberately added. In a certain level of soil damage, agricultural management employed might unable to balance the production cost. Plantation in this land then usually abandoned and the farmers usually try to find a new fertile soil. In many cases, the new fertile soils are found in the forest and a new plantation is then developed by cutting more trees in that forest.

Abandoned plantation is commonly found in area where production constraint could not be solved. For example, in South America and Africa, thousand hectare of cacao plantation were abandoned after regarded as unproductive because of diseases. Other than biological factors, environmental stress such as drought could enhance this plantation to become unproductive. So, shifting traditional agricultural system into a massive production system is usually using robust agricultural practices which could then develop more bare soil (Tscharntke et al. 2011). Because of high evaporation rate from the bare soil, crops will be easily exposed to water stress. These plants could also encounter nutrient deficiency because high rate of nutrient run off. Although these two factors, i.e. water and nutrient, are regarded as the main constraint for plants growth (IAEA 2008), the loss of soil moisture are usually neglected (Saxson and Barber 2003).

Figure 3. Performance of vanilla plants after ca 9 month of growth with addition of mulch (Adiputra, unpublished data).

By contrast, although resources for minimizing the loss of soil moisture are readily available locally in the plantation, but the resources are not deliberately collected to mulch the crop plants. For example, litter of dry leaf and twig, grass clipping, coconut frond, are plenty but it is not utilized as mulch to increase the retention of soil moisture. Furthermore, although organic mulches are known as important nutrient source, farmers prefer to apply synthetic fertilizer which easily to run-off in plantation with a depleted soil carbon.

In view of soil moisture and fertilities, intensification of mulching using agricultural by product could become an efficient method to heal soil after experiencing robust agricultural practices. Accordingly, a preliminary study is being conducted to see the effect of organic mulching on the growth of vanilla plants. These experimental plants were added whether dry leaf, woods or grass clipping, commenced on August 2016 (Fig. 2). After about 9 months of mulching, those vanilla plants are showing a healthy growth (Fig. 3). This preliminary study at least indicating that mulching does not inhibit the growth of vanilla plants (Adiputra, unpublished data).

3. Depleted soil organic carbon (SOC) reduced crop yield because of water shortage

Most water required by plant is taken up from soil via the root systems. For the uptake, water potential different between soil and root is it driving force (Taiz and Zieger 2002). Since water potential depends on concentration of ions, the rate of water uptake is related to the uptake of mineral also from soils. Mineral ions in the soil are actively taken up via plasma membrane resulted in the decreasing of water potential in the root. This lower water potential then pulls soil water to flow into the roots. According to Herrera-Estrella (2011), decreasing water potentials in leaves which attributed by transpiration of water via stomata are then pull water from the root to flow via xylem into the leaves. With the present of hydrogen bonds among the water molecules, water uptake in the root and water transpired in the leaves are very closely connected in the xylems.

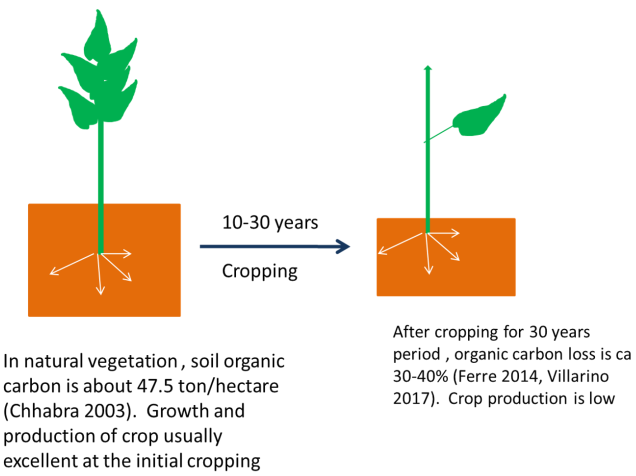

Figure 4. Conversion of natural vegetation into plantation resulted in the decreased of soil organic carbon.

It has widely been acknowledged that water is not only a substrate for photosynthesis but also as medium and transporting system in plants. For a normal growth, plants could require 500 g of water from soil to synthesize 1 gram of organic compound in the plant (Taiz and Zieger 2002). So, the relatively huge amount of water is required by plants to produce organic compound suggesting that soil moisture is becoming vital for crop yield. For example, to produce 1 kg of cacao seeds, the plants require ca 500 litre of water from soil. The amount of water available for plants to grow is affected by various complicated factors. One of the factors is global warming.

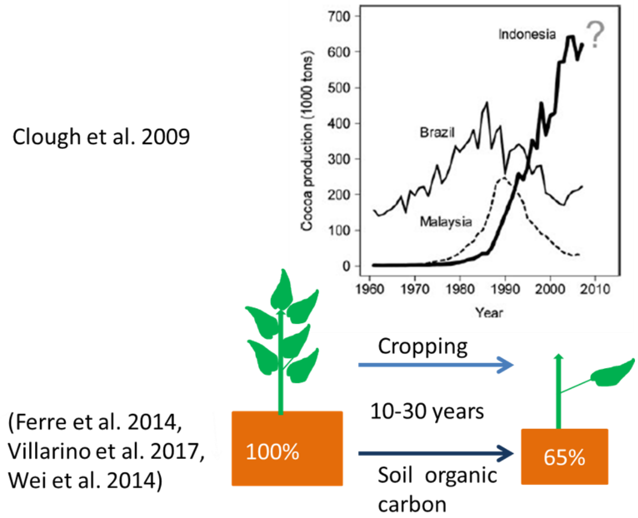

Figure 5. The decrease of crop yield and soil organic carbon. The onset of decrease in yield occur 30 years after cropping (Clough et al. 2009) when organic carbon remaining in the soil only ca 65%.

Under condition of global warming scenario, landscape plants could suffer a severe drought attributed by high rate of evaporation which in turn causing over precipitation in other regions (Amedie 2013). These conditions could become worst if forest, which naturally produce mulch materials and naturally covers the soil surface (Bell et al. 2009), are continuously diminish and leaving more bare lands (for a review see Measley 2010). Chalker-Scott (2007) point out that mulch was found effective in term of water conservations, but there has been no scientific research on landscape mulches. In other cases, a cycle of wet and dry seasons continuously occurs in tropical area and water shortage as the main constraint for plant growth is usually occurred during dry season. Shallow rooted plants, like vanilla, could undergo a severe water stress during this period depending on the duration of dry seasons. Under these water shortage conditions, an intensive agricultural management is required to sustain longer soil water retention. However, most small holder farmers are unable to afford high tech irrigation system to collect water from remote area. Fortunately, traditional irrigation systems which collect water from remote area are still maintained in some regions. For example, *subak* in Bali is a genuine system that could maintain water supply into rice plants. Even though, unlike rice production in paddy field, crop yield in landscape plants relay its water supply only from the amount of water that can be hold in soil moisture. In this dry land crops, the capacity of soil to hold water is becoming crucial.

According to Fountain and Durham (2016), a proper amount of water is far more important than fertilizer in landscape plants. These authors also point out that percolation is a key survival for landscape plants. Implying that maximizing the capacity of soil to percolate and hold water is critical to crop yield in landscape agriculture. Since this capacity depend on soil organic carbon (Rawls et al. 2003), maintaining crop yield in landscape agriculture require the maintenance of soil organic carbon.

4. Intensification of mulching to improve soil moisture and crop yield

Carbon sequestration, a process of storing organic carbon in the soil, is part of a global carbon cycle (Chan 2008). CO_2 from atmosphere are taken up by plants via stomata before synthesizing into organic carbon in the plants using water as raw materials. Dry material from the plants then stored in the soil as organic carbon before mineralized by bacteria. This mineralization releases back CO_2 into the atmosphere. The duration of organic carbon present in the soil is depended on various factors include; rain fall, temperature, soil type and soil management.

In natural vegetation of tropical forest, soil organic carbon is ca 47.5 t/ha (Chhabra et al. 2003). This amount could then change after conversion of forest into agricultural land. Studied reported by Ferre et al. (2014) showed that soil organic carbon was decreased to ca 40% after 37-year conversion of natural forest into poplar plantations. In other case, large area of dry forest had been clear for crop expansion in Argentina. Study conducted on this crop land show that after 10 years of cropping, soil organic carbon loss is ca 30% (Villarino 2017). Similar result was also reported by Wei et al. (2014). According to these authors, conversion of forest for cropping reduces 37.4% of soil organic carbon in tropical region after 10 years of cultivation. From those various studies, in the average, soil organic carbon loss is about 34.9 % after conversion of natural forest into plantation for 19 years (Fig. 4).

If this soil organic carbon represents the capacity of soil to hold waters, after conversion of forest into plantation, the capacity of soil then remains only ca 65%. This capacity might not sufficient to maintain soil moisture required for optimal production of cacao. Therefore, as has been reported by Clough et al. (2009), cacao production subsequently then burst after 30 years of production. A sharp decrease of cacao production after 30 years period (Fig. 5) strongly indicate that sustainability of crop yield depends on sustainability of soil organic carbon. This particularly because soil organic carbon is very important for soil moisture and fertility (Chan 2008). If this possibility is correct, maintaining vanilla production should require much higher soil organic carbon to hold more water in the soil, since vanilla has much shallower root system than cacao. Thus, maintaining a higher soil organic carbon is becoming very important for sustainable vanilla plantation.

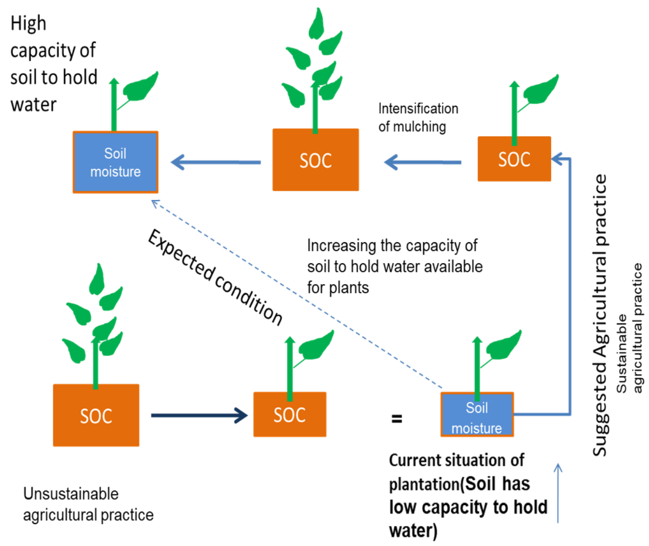

Figure 6. Compilation of study from various literatures (Ferre 2014, Villarino 2017, Chan 2008, Manu *et al*. 2017). This compilation suggests that soil moisture in lower soil organic carbon can be improved by intensification of mulching to improve plant growth and crop yield.

According to Chan (2008), there are wide ranges of option to maintain soil organic carbon. Those options include retaining crop residue and application of organic amendments. Manure, plants debris and compost, which contain high concentration of organic carbon, could increase input to the plantations. For example, addition of mulches into the soil surface could increases soil organic carbon in agricultural lands (Bojoriene et al. 2013). Ferrara et al. (2011) had suggested to use organic mulches for sustainable farming. Dickie et al. (2014) then arguing that mitigation in 3 potential sectors i.e. emission reductions, sequestration of carbon in agricultural system and shift in consumption patterns would make agricultural GHG neutral. Thus, to sustain crop yield under condition of global warming, various agricultural practice should be modified, particularly addition of organic mulch to improve soil organic carbon and soil moisture (Fig. 6).

The longer duration of soil moisture, the plant could maintain a longer period of normal physiological mechanism. This normal plant function then greatly enhance growth and defend system, particularly for shallow rooted plants such as vanilla. Thus, sustainability of vanilla production most likely can be maintain by intensification of mulching.

5. Conclusions

The amount of water in soil that available for uptake by shallow rooted plants such as vanilla is very sensitive to environmental changes. Global warming and unsustainable agricultural practices diminishes soil organic carbon and soil moisture which subsequently reduce capability of plants to maintain normal function. Since addition of mulches could maintain longer duration of soil moisture, as has been shown by various studies, sustainable vanilla production can be maintained by intensification of mulching.

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