The Effect of Accumulation of Leaf Litters and Allelochemicals in the Soil to the Sustainability of the Newly Introduced Crop Plants

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Review Article

The Effect of Accumulation of Leaf Litters and Allelochemicals in the Soil to the Sustainability of the Newly Introduced Crop Plants

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ABSTRACT
Indonesia is the second-largest vanilla production and the third-largest cocoa production in the world, but it sustained for a short period. The unsustainability of these crops is speculated to occur because of the change in leaf litter accumulation which affected the sustainability of soil organic carbon that plays an important role in maintaining soil health and fertility. To find out methods that could improve the sustainability of the production, a literature review was conducted. The articles, related to the sustainability of vanilla and cacao production, were collected using Google Scholar, Wiley Online Library, ResearchGate, and Google Chrome browser. Keywords were employed to find the articles including soil organic carbon, cocoa plantation, vanilla, leaf litter, and allelochemical. This current article review found that introducing crop by clearing of previously existing vegetation could severely reduce the rate of leaf litter accumulation. Consequently, in a prolonged period, the soil organic carbon and soil fertility are very low and are unable to support the healthy growth and production of the crops. To restore production, the plantation then is returned to more traditional agroforestry such as replanting shading trees and addition of mulch. However, in the higher density of canopy, the crop production is low attributed partly to the decreasing soil pH which increases the impact of allelochemical. This review concluded that the sustainability of leaf litter accumulation is crucial to maintain soil health, but mitigation is required to reduce the impact of allelochemical accumulation.

INTRODUCTION

Indonesia is the second-largest vanilla production in the world after Madagascar (Arya & Lenka 2019), but this achievement is not sustainable as the case found in Bali (Figure 1). The production was slowly increased into the top production and then decreased very sharply. The ensuing increase in production was not found for more than 5 years after the top production (BPS Bali. a). Indonesia is also an important cacao producer, the 3rd largest in the world, but the production is also not sustainable (Schaad & Fromm 2018). In Bali, the production of cacao was showing a slightly similar trend to that of vanilla production, i.e. slow increased into top production and followed by a sharp decrease (BPS Bali. b). The period of decreasing production occurred for ca. 4-5 years (Figure 1). Since these two crops, particularly cacao, is the source of income for millions of smallholder farmer and family in Indonesia, a majority in Sulawesi Island (Witjaksono & Asmin 2016), the sustainability of these crop production is regarded as very important to be maintained. Various factors may involve in the fluctuation of production, but this review focusing discussion on the accumulation of leaf litter and allelochemical in the plantations to find out sustainable methods. Both, the accumulation of leaf litter and allelochemical are related since the accumulation of leaf litter decreases soil pH and increases the impact of allelochemical.

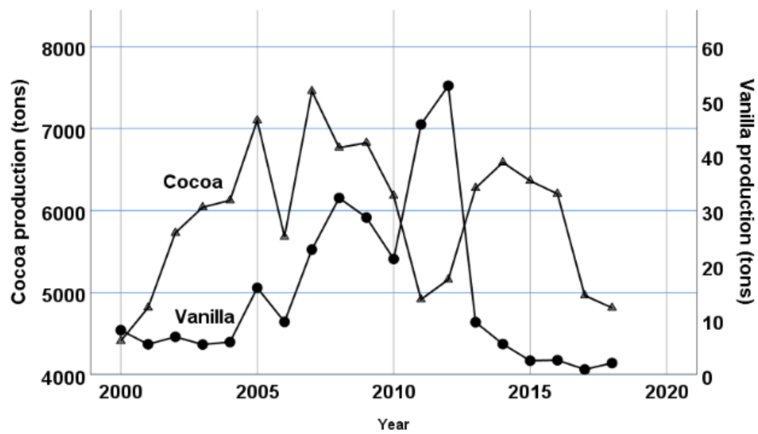

Figure 1. Production of vanilla and cacao in Bali from 2000-2018. Data were collected from BPS Bali (https://bali.bps.go.id/dynamictable).

This study is regarded as very important, firstly, it is because clearing up trees before the introduction of new crops will cut off organic carbon supply from the leaf litter of the trees which subsequently could deteriorate soil organic carbon. This organic carbon is responsible for soil health and fertility. Secondly, clearing up trees affects the hydrological mechanism and leads to drought during the dry season and flooding during rainy seasons. After the plantation then unproductive, the abandoned landscape is unable to support people economically and environmentally.

MATERIALS AND METHODS

This review was written after reading and understanding literature collected using search engines, such as Wiley Online Library, Google Scholar, Research Gate, and Google Chrome browser. Free access relevant articles from a journal found in those search engines were then opened and downloaded. There were more than 100 articles found related to leaf litter, soil organic carbon, cacao production system, allelochemical, and nutrient release from decomposing plant materials. About 30 papers were selected for this review based on the publishing date and its relevance to the written topic. Data collected from these papers include leaf litter accumulation and soil organic carbon level, the decomposition rate of leaf litter, and the type of allelochemical produced by plants. Each data variable was then analyzed descriptively and presented in tables.

RESULTS AND DISCUSSION

Leaf litter accumulation and soil organic carbon level

The trees vegetation in agroforestry could produce a substantial amount of leaf litter (Table 1) which becomes an important source of soil organic carbon and nutrients (Ampitan et al. 2021; Ledo et al. 2020; Sauvadet et al. 2020; McGrath et al. 2000; Mehta et al. 2013; Mutshekwa et al. 2020). Whilst soil organic carbon improves soil porosity and water percolation, the increased amount of available nutrient in soil improve growth and production of the crop (Shaxson & Barber 2003; Sanz et al. 2017).

Table 1. The accumulation of leaf litter in various types of vegetations. By using litter traps, accumulation of leaf litter was observed for 1-2 years and using carbon dating, the accumulation of carbon was observed for 256 years.

No	Type of vegetation	Tree species	Leaf litters (kg/ha)	References
1	Dry forest	*Cordia alba*	1134	(Castellanos-Barliza et al. 2018)
2	Boreal forest		7250	(Kyaschenko et al. 2019)
3	Agri-horti-silvi culture	Okra, Manggo, Teak	831.25	(Singh et al. 2019)
4	Cacao plantation	Cacao	3130	(Muoghalu & Odiwe 2011)
5	Agroforest tree	*Celtis australis*, *Grewia optiva*, *Bauhinia variegata* & *Ficus roxburghii*	2190	(Singhal et al. 2019)

Relative to the boreal forest, the accumulation of leaf litters in the plantation is much lower (Table 1). In cacao plantations (Muoghalu & Odiwe 2011), the production of leaf litter was about 43 % of that found in the boreal forest (Kyaschenko et al. 2019). In agri-silviculture, the accumulation of leaf litter reported was 831.25 kg/ha (Singh et al. 2019), but in the boreal forest, the accumulation was 7250 kg/ha (Kyaschenko et al. 2019). The data indicated that decreasing plant diversity in the plantation relative to the diversity of plants in native forest resulted in a decrease amount of leaf litter accumulation. This decrease subsequently then reduces soil organic carbon which is very important for the soil health and nutrient available in the soil.

The contribution of leaf litter to the accumulation of soil organic carbon has widely been studied. Novara et al. (2015) reported that the addition of leaf litter to soil increased soil organic carbon by up to 13% relatively to the soil without the addition of leaf litter. This increase in soil organic carbon is mainly attributed to worm activity. More recent reports (Liebmann et al.

2020) show that the contribution of litter to mineral related organic carbon in topsoil was 1.88 g C m^{-2} for 22 months which is equal to ca 18.800 kg C Ha^{-1}. Therefore, soil organic carbon in the plantation is lower than in the forest after the conversion of forest into cropland (Aryal et al. 2018; Kassa et al. 2017; Machado et al. 2017) have taken into account to sustain the newly introduced crop production.

Under the various conditions of the agricultural system employed and the type of crop introduced, the landscape of the crops might continuously deteriorate which eventually makes the soil unable to provide a healthy growth condition. This deterioration can be estimated by assuming that crop production is linearly correlated with the soil conditions. In cacao plantations, the deterioration is commenced ca 6 years after the initial productions which are indicated by a sharp decrease in productions (Figure 1). This sharp decrease occurred just after the crop showing the top productions. In the vanilla plantation, the deterioration is commenced ca 4 years later than that in cacao plantation. This is very likely attributed to the higher commercial yield produced by cacao, i.e. more than 7000 tons rather than vanilla, i.e. ca 55 tons during the period of the first top production. The removal of the yield from the plantation, particularly during the top production, possibly causes a substantial decrease of nutrients available in the soil. Although this nutrient loss could be replenished by increasing input, such as fertilizer, the decrease of soil organic carbon content is unable to be replenished instantly.

In the ensuing period, production of cacao can still be restored but the top production is about 870 tons lower than the first top productions. Unlike the cacao, in vanilla plantations, restoring production did not occur for more than 5 years. Indicating that the deterioration of soil growth medium in the crop landscape is relatively hard to heal possibly because the agricultural system employed does not support the sustainability of soil organic carbon which is regarded as central to soil health (Ramesh et al. 2019). Thus, the addition of mulch to a crop plantation draws more attention to the sustainable production of the crop (Shaxson & Barber 2003). For example, to heal the landscape in cacao production, Acheampong et al. (2019) have experimented by mulching cocoa plants using coffee husk. These authors concluded that simple mulching techniques could significantly improve the cropping of cacao. The other experiment was reported by Riedel et al. (2019) using agroforestry and rehabilitation pruning. These authors highlight the potential of agroforestry to reconcile ecologically sustainable land. Since both mulching and agroforestry improve soil organic carbon, those experiments suggesting that the sustainability of cacao production can be improved by maintaining soil organic carbon. For sugarcane crops, it was estimated that sustaining soil organic carbon after the removal of crop yield requires the addition of ca 3 ton/ha organic materials (Gmach et al. 2021). This kind of technique may become an important method for improving the sustainability of cacao or vanilla plantations.

Soil fertility

Litterfall and litter decomposition are key elements of nutrient cycling in tropical forests (Cole et al. 2020; Froufe et al. 2020; Castellanos-Barliza et al. 2018; Mehta et al. 2013). Before providing crop plants with nutrients, the leaf litter produced by trees in plantations undergo a complex interaction with soil involving biotic and abiotic factors (Keller & Phillips 2019). This interaction which then leads to leaf litter decomposition is also affected by the type of agricultural system employed (Sauvadet et al. 2020). In agroforest cocoa plantation, the time required for 99% leaf litter decomposition was 2.6 years, much faster than in conventional cocoa plantation, i.e. 3.5 years (Asigbaase et al. 2021). This is indicating that the supply rate of organic carbon into the soil of agroforest plantations was faster than the supply in the conventional plantations. This enhancement, according to the authors, is attributed to the improvement of soil conditions. It has been acknowledged that under harsh environmental conditions such as low temperatures, waterlogging, anoxic, acidic sites, and drought, the decomposition rate of leaf litter is low (Aerts et al. 2012; Xie et al. 2020). The faster accumulation and subsequent decomposition of leaf litter in agroforestry, the likely make higher soil perforation enables better drainage and lengthens soil moisture. This mechanism is in agreement with reports which showed that forest soil has the highest soil perforation and moisture followed by agroforestry and pasture (Suárez et al. 2021). This is also indicating that higher plants diversity in plantations resulted in more healthy soils. Among the type of trees, the decomposition rate is varied (Table 2).

Table 2. The decomposition rate of leaf litter in various plant vegetations.

No	Plant type	Decomposition rate (k)	References
1	*Theobroma cacao*	1.03	(Muoghalu & Odiwe 2011)
2	*Grewia optiva*	2.12	(Singhal et al. 2019)
3	*Celtis australis*	2.30	
4	*Bauhinia variegate*	1.64	
5	*Ficus roxburghii*	1.05	
6	Angiospermae (include Magnoliid)	2.52	(Liu et al. 2014)
7	Eudicot	6.18	

Since the supply rate of nutrients available in the soil is the function of the rate of the leaf litter decomposition, the sustainability of crop production in a plantation then depended upon the type of shading tree in the crop plantation. The crop plant or shading tree that produces leaves with a high decomposition rate will provide nutrients faster than the plants that produce leaf with a lower decomposition rate. For example, the decomposition rate of cacao leaf was 1.03 (Muoghalu & Odiwe 2011) and the decomposition rate of Angiospermae was 2.52 (Liu et al. 2014). Assuming that cacao plantation is developed using a monoculture system and Angiospermae trees are also grown in a monoculture, the time taken by the cacao plants to acquire recycled nutrients was twice longer than the Angiospermae plantation. Consequently, if the cacao plantation is established by clearing off previous vegetation, the supply of soil organic carbon into the soil will undergo a lag period for a relatively long period which then deteriorates the previously accumulated soil organic carbon. Resuming process by the cacao plants is very low and after reaching a certain low soil organic carbon level, the soil could not provide a condition for healthy production. This includes soil moisture and nutrient available in the soil. The production then drops sharply and the plantation is then abandoned because of its economically inefficiency. It is speculated that by establishing cacao plantation in an agroforest system that consists of crop plants and forest trees, the supply of leaf litter can be maintained which subsequently provided soil with richer amount of organic carbon and nutrients.

However, although the agroforestry system provided a healthier growth medium for the crop plants, the type of nutrient release and environmental condition generated by the shading trees might not complement the requirement or growth condition of the crop. This is particularly because the nutrient requirement of a particular crop is specific to species. Various studies have been reported which showed various organic carbon, fertility, and nutrients content in different vegetation diversity. Suárez et al. (2021) evaluated soil quality in various agroforestries in the Colombian Amazon. They found that the general indicator of soil quality is decreasing from forest, agroforestry, and pasture. Importantly, these authors found that the establishment of agroforest cacao plantations improves soil fertility by 42% relatively to degraded pasture. Matos et al. (2020) reported that litter quality supported the restoration of soil and Saputra et al. (2020) reported that complex agroforest increases soil organic carbon. These studies collectively showed that the more diverse the plant population, the higher soil organic carbon level and soil fertility.

In the native forest, N content in soil was higher than in the plantation (Machado et al. 2017), but in pasture monoculture, potassium was released at a higher level (Piza et al. 2021). The type of nutrient in leaf litter produced by non-agroforest and by different agroforest was studied by Rangel-Mendoza and Silva-Parra (2020). This study compares the concentration of N, P, Ca, Mg, K and it is found that leaf litter collected from mixed Cacao-*A. peregrina* L agroforestry contains a higher concentration of N, P, Mg and K. This is indicating that different types of vegetation provided different supplemental nutrients for the growth of crop plants and it was improved after the diversity of vegetation is increased. However, a very basic question remains unanswered whether or not the improvement of the soil health linearly correlated with the crop yield as previously been proposed.

The accumulation of allelochemicals in plantation

The agroforestry system is not a new system for vanilla plants because of their growth characteristics. The vanilla plants are naturally grown in mixed culture with trees as tutor or shading plants. Therefore, related to a monoculture cacao plantation, the accumulation of soil organic carbon and nutrient in the vanilla plantation can be considered as healthier. However, the yield of the vanilla plants is also not sustainable, as the case found in Bali (Figure 1). So, it is speculated that other factors associated with leaf litter, i.e. allelochemical, could also become an important constraint for the growth and production of crops. The increasing amount of leaf litter accumulation in the soil makes soil not only rich in organic carbon and nutrient but also allelochemical. This is particularly because the compound is also present in the leaf (Iqbal et al. 2019). The higher amount of leaf litter accumulation, the more likely allelochemical accumulated in the soil and the impact is more severe.

Plants have long been known to produce various organic compounds to encounter adverse environmental conditions, such as drought, light, disease, and predators. The chemical compounds are known as secondary metabolites comprised of phenolic compounds, alkaloid, and terpenoid (Macías et al. 2019). A group of organic compounds that are released into the environment for inhibiting the growth of other plants is known as allelochemical. This compound can be released via volatilization from leaves, exudation from the root, and leachate or release from plants residue (Zhang et al. 2021). According to these authors, allelochemical released from plant residue has the most negative effect on the performance of recipient plants since the allelochemical consist of whether water or non-water-soluble compounds.

In plants, this toxic allelochemical may be stored in a membrane-bound vesicle or released via the root system into the apoplast by exocytosis (Bonanomi et al. 2006; Weston et al. 2012). The other allelochemical is produced and stored in leaves and then it released into the environment during leaf litter degradation. Toxicity of the allelochemical is rapidly decreased under aerobic condition but it is increasing and becoming stable under anaerobic condition (Bonanomi et al. 2006). Suggesting that crop plants developed in an anaerobic condition, such as water logging during prolonged rain seasons, will encounter an increasing number of toxic compounds when the accumulation of leaf litter increased. Therefore, since the leaf litter accumulated on the soil surface could be originated from the crop itself, both agroforestry and monoculture systems will be facing the allelochemicals problems. This is particularly because toxic compounds previously stored in a membrane-bound vesical in plants are then released freely into environments during decompositions. This toxic compound could inhibit the root system of whether the crop or the shading trees. Allelochemical released by the crop and inhibited the growth of the crop is known as autotoxicity. This mechanism could substantially reduce crop yield (Singh et al. 1999). The other toxic compound could also inhibit the growth of other plants. Zhang et al. (2015) reported that leaf litter from different plants species affected differently to the growth of seeds. For example, extract from *Populus canadensis* inhibited the growth of rape seed, but the extract from *Prunus persica* was beneficial to the germination of the rape. Indicating that a plant species may be sensitive or tolerant to an allelochemical produced by other species.

Deheuvels et al. (2012) had previously reported that the production of cacao was lower in plantations using a high density of canopy rather than in high-density cocoa plants. These results deviate from the previous discussion which showed that agroforestry increases soil organic carbon and nutrient which should support a higher yield. The high organic carbon in the soil also increased soil porosity which makes the soil healthier, i.e. it is more aerobic and lengthens soil moisture. Thus, the negative correlation between soil health and crop yield, under the high density of canopy (Deheuvels et al. 2012), is very unlikely attributed to the increase of soil organic carbon and nutrient nor by soil porosity. One of the various possible causes is the presence of allelochemical release from leaf litter of the crop and the canopy. According to Bonanomi et al. (2006), the effect of allelochemical is increased in anaerobic soil conditions and in lower soil pH levels. So, the lower cacao production in the higher density of canopy, most likely caused by lowering soil pH level which increases the toxicity of allelochemical. This possibility is in agreement with the report by Fang et al. (2017) which showed that soil pH was lower under the condition of higher soil organic carbon and a report by Cornelissen et al. (2018) which showed that crop yield positively correlated with soil pH.

In other studies, Bhowmik & Doll (1982) showed that the addition of corn residue reduced corn production and the addition of soybean residue reduced production of soybean. It is suggested that allelochemical originated from the crop could also inhibit the root physiology of the crops themselves. This also indicates that allelochemical previously stored in a safe vesical in plants then can be dangerous for the plants after it is released into the environment during leaf litter decompositions. This possibility then can be inferred for cacao productions, since cacao plantations accumulated ca 3130 kg/ha/year leaf litters (Muoghalu & Odiwe 2011). Under the condition of anaerobic and low soil pH, the impact of allelochemical released by cacao leaf could be substantial to inhibit production. Therefore, to sustain productivity, whether, in agroforest or monoculture, soil porosity and good drainage are required to enhance aeration and to improve soil pH level. In acidic soil, the application of biochar or charcoal has been found to improve soil pH and plant growth (Cornelissen et al. 2018).

The impact of the toxic compound is reported more severe in a shallow-rooted crop than in deep-rooted crops (Chalker-Scott 2007) which highlighted the difference between cocoa and vanilla. Unlike cacao plants which have relatively deeper-rooted systems, vanilla plants that belong to the orchid family are shallow-rooted plants and rarely shed their leaves. So, the contribution of vanilla leaf litter to the landscape is much lower than that of cacao leaves litter. Accordingly, less amount of allelochemical was originated from leaf litter of the vanilla plants. However, because vanilla is a shallowed-rooted plant, they are very sensitive to drought and mulching is regarded as crucial to inhibit water loss from the soil surface. Allelochemicals that could inhibit the growth of vanilla are most likely originated from shading trees and mulch materials. Vanilla plants are mulched with various types of plants materials, such as coconut husk, leaf litter of various trees, etc. Under the condition of anaerobic and lower pH, allelochemical from the shading trees and mulch materials could also affect the growth of vanilla. Metabolites produced by the shading trees and mulch material that potentially inhibit the growth of vanilla are shown in Table 3.

The effect of mulching on the vegetative growth of vanilla plants has been reported (Adiputra et al. 2019). This study showed that the growth of vanilla was reduced by the addition of taro clippings but increased by the addition of dry leaf and coconut husk mulch. These authors concluded that vanilla plants are sensitive to allelochemical released by taro clipping but tolerant to allelochemical released by dry leaf and coconut husk.

CONCLUSION

Maintaining soil organic carbon level previously existed in the plantation is required to improve the sustainability of the newly introduced crop. This can be achieved by retaining the tree population and addition of mulch. However, since the increase of organic carbon could decrease soil pH which increased the negative effect of allelochemical, the addition of biochar or charcoal is regarded as crucial to increase soil pH.

AUTHORS CONTRIBUTION

I G.K. Adiputra. read and understanding relevant articles which are searched and downloaded using search engines before written into a manuscript.

Table 3. Type of allelochemical released by plants species

No	Plant Family	Species	Compounds	Reference
1	Arecaceae	*Cocos nucifera*	Phenolic compounds	(Gonçalves et al. 2019)
2	Dennstaedtiaceae	*Pteridium Gled. Ex Scop*	Selligueain A	(De Jesus Jatoba et al. 2016)
2	Rubiaceae	*Coffee arabica*	Caffeine	(Asfew & Dekebo 2019)
3	Fabaceae	*Gliricidia sepium*	Coumarine	(Takemura et al. 2013)
4	Moraceae	*Artocarpus heterophyllus*	Aqueous methanol extract	(Noguchi & Takami 2015)
5	Araceae	*Colocasia esculenta*	Benzoic acid	(Asao et al. 2003)
6	Moraceae	*Artocarpus heterophyllus*	squalene	(Biswas & Chakraborty 2013)
7	Sterculiaceae	*Theobroma cacao*	Theobromine, Polyphenol	(Hii et al. 2009)
8	Fabaceae	*Leucaena leucocephala*	Mimosine	(Sahid et al. 2017)

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CONFLICT OF INTEREST

There is no competing interest regarding the manuscript.

REFERENCES

Acheampong, K. et al., 2019. Improving field establishment of cacao (Theobroma cacao) through mulching, irrigation and shading. *Experimental Agriculture*, 55(6), pp.898–912. doi: 10.1017/S0014479718000479.

Adiputra, I.G.K., Winaja, I.W. & Sumarya, I.M., 2019. Vegetative growth of vanilla cuttings after addition of weed clippings mulch under 2 climatic condition, wet and dry seasons. In *IOP Conference Series: Earth and Environmental Science*. Institute of Physics Publishing. doi: 10.1088/1755-1315/399/1/012084.

Aerts, R., van Bodegom, P.M. & Cornelissen, J.H.C., 2012. Litter stoichiometric traits of plant species of high-latitude ecosystems show high responsiveness to global change without causing strong variation in litter decomposition. *New Phytologist*, 196(1), pp.181–188. doi: 10.1111/j.1469-8137.2012.04256.x.

Ampitan, T.A. et al., 2021. Effect of litter mineralisation on soil, under Acacia senegal (Wild L) plantation in the semi-arid zone of Nigeria. *Ethiopian Journal of Environmental Studies & Management*, 14(1), pp.74–83. doi: https://ejesm.org/doi/v14i1.6.

Arya, S.S. & Lenka, S.K., 2019. (PDF) Vanilla Farming: The Way Forward. *Eden Horti*, 2(3), pp.20–24. doi: 10.13140/RG.2.2.18451.02087.

Aryal, D.R. et al., 2018. Soil organic carbon depletion from forests to grasslands conversion in mexico: A review. *Agriculture (Switzerland)*, 8(11), pp.1–15. doi: 10.3390/agriculture8110181.

Asao, T. et al., 2003. Autotoxicity of root exudates from taro. *Scientia Horticulturae*, 97(3–4), pp.389–396. doi: 10.1016/S0304-4238(02)00197-8.

Asfew, Z. & Dekebo, A., 2019. Wollega Zones of Ethiopia by high performance liquid chromatography Trends in Phytochemical Research (TPR). *Trends Phytochem. Res*, 3(4), pp.261–274.

Asigbaase, M. et al., 2021. Decomposition and nutrient mineralisation of leaf litter in smallholder cocoa agroforests: a comparison of organic and conventional farms in Ghana. *Journal of Soils and Sediments*, 21(2), pp.1010–1023. doi: 10.1007/s11368-020-02844-4.

Bhowmik, P.C. & Doll, J.D., 1982. Corn and Soybean Response to Allelopathic Effects of Weed and Crop Residues 1. *Agronomy Journal*, 74(4), pp.601–606. doi: 10.2134/agronj1982.00021962007400040005x.

Biswas, S.M. & Chakraborty, N., 2013. Shedded Artocarpus leaves - Good plant sources of natural squalene with potent antioxidant and antimicrobial activity - Alternative to marine animals. *Journal of Natural Pharmaceuticals*, 4(1), p.21. doi: 10.4103/2229-5119.110344.

Bonanomi, G. et al., 2006. Phytotoxicity dynamics of decaying plant materials. *New Phytologist*, 169(3), pp.571–578. doi: 10.1111/j.1469-8137.2005.01611.x.

BPS Bali. a, Produksi Panili Menurut Kabupaten/Kota di Provinsi Bali. Available at: https://bali.bps.go.id/indicator/54/356/7/produksi-panili-menurut-kabupaten-kota-di-provinsi-bali.html.

BPS Bali. b, Produksi Kakao Menurut Kabupaten/Kota di Provinsi Bali. Available at: https://bali.bps.go.id/indicator/54/352/1/produksi-kakao-menurut-kabupaten-kota-di-provinsi-bali.html.

Castellanos-Barliza, J. et al., 2018. Contributions of organic matter and nutrients via leaf litter in an urban tropical dry forest fragment. *Revista de Biologia Tropical*, 66(2), pp.571–585. doi: 10.15517/rbt.v66i2.33381.

Chalker-Scott, L., 2007. Impact of Mulches on Landscape Plants and the Environment — A Review. *Journal of Environmental Horticulture*, 25(4), pp.239–249. doi: 10.24266/0738-2898-25.4.239.

Cole, R.J. et al., 2020. Litter dynamics recover faster than arthropod biodiversity during tropical forest succession. *Biotropica*, 52(1), pp.22–33. doi: 10.1111/btp.12740.

Cornelissen, G. et al., 2018. Fading positive effect of biochar on crop yield and soil acidity during five growth seasons in an Indonesian Ultisol. *Science of the Total Environment*, 634(0806), pp.561–568. doi: 10.1016/j.scitotenv.2018.03.380.

Deheuvels, O. et al., 2012. Vegetation structure and productivity in cocoa-based agroforestry systems in Talamanca, Costa Rica. *Agriculture, Ecosystems and Environment*, 149, pp.181–188. doi: 10.1016/j.agee.2011.03.003.

Fang, X. et al., 2017. Forest-type shift and subsequent intensive management affected soil organic carbon and microbial community in southeastern China. *European Journal of Forest Research*, 136(4), pp.689–697. doi: 10.1007/s10342-017-1065-0.

Froufe, L.C.M. et al., 2020. Nutrient cycling from leaf litter in multistrata successional agroforestry systems and natural regeneration at Brazilian Atlantic Rainforest Biome. *Agroforestry Systems*, 94(1), pp.159–171. doi: 10.1007/s10457-019-00377-5.

Gmach, M.R. et al., 2021. Soil dissolved organic carbon responses to sugarcane straw removal. *Soil Use and Management*, 37(1), pp.126–137. doi: 10.1111/sum.12663.

Gonçalves, F.A. et al., 2019. Valorization, Comparison and Characterization of Coconuts Waste and Cactus in a Biorefinery Context Using NaClO2 –C2H4O2 and Sequential NaClO2–C2H4O2/Autohydrolysis Pretreatment. *Waste and Biomass Valorization*, 10(8), pp.2249–2262. doi: 10.1007/s12649-018-0229-6.

Hii, C. et al., 2009. Polyphenols in cocoa (Theobroma cacao L.). *As. J. Food Ag-Ind*, 2(204), pp.702–722. Available at: www.ajofai.info.

Iqbal, A. et al., 2019. Plants Are the Possible Source of Allelochemicals That Can Be Useful in Promoting Sustainable Agriculture. *Fresenius Environmental Bulletin*, 28(2A), pp.1052–1061.

De Jesus Jatoba, L. et al., 2016. Allelopathy of bracken fern (pteridium arachnoideum): New evidence from green fronds, litter, and soil. *PLoS ONE*, 11(8), pp.1–16. doi: 10.1371/journal.pone.0161670.

Kassa, H. et al., 2017. Impact of deforestation on soil fertility, soil carbon and nitrogen stocks: the case of the Gacheb catchment in the White Nile Basin, Ethiopia. *Agriculture, Ecosystems and Environment*, 247(July), pp.273–282. doi: 10.1016/j.agee.2017.06.034.

Keller, A.B. & Phillips, R.P., 2019. Leaf litter decay rates differ between mycorrhizal groups in temperate, but not tropical, forests. *New Phytologist*, 222(1), pp.556–564. doi: 10.1111/nph.15524.

Kyaschenko, J. et al., 2019. Soil fertility in boreal forest relates to root-driven nitrogen retention and carbon sequestration in the mor layer. *New Phytologist*, 221(3), pp.1492–1502. doi: 10.1111/nph.15454.

Ledo, A. et al., 2020. Changes in soil organic carbon under perennial crops. *Global Change Biology*, 26(7), pp.4158–4168. doi: 10.1111/gcb.15120.

Liebmann, P. et al., 2020. Relevance of aboveground litter for soil organic matter formation - A soil profile perspective. *Biogeosciences*, 17(12), pp.3099–3113. doi: 10.5194/bg-17-3099-2020.

Liu, G. et al., 2014. Understanding the ecosystem implications of the angiosperm rise to dominance: Leaf litter decomposability among magnoliids and other basal angiosperms. *Journal of Ecology*, 102(2), pp.337–344. doi: 10.1111/1365-2745.12192.

Machado, M.R. et al., 2017. Modificações na cobertura vegetal influenciam os atributos químicos do solo na Amazônia brasileira. *Acta Scientiarum - Agronomy*, 39(3), pp.385–391. doi: 10.4025/actasciagron.v39i3.32689.

Macías, F.A., Mejías, F.J.R. & Molinillo, J.M.G., 2019. Recent advances in allelopathy for weed control: from knowledge to applications. *Pest Management Science*, 75(9), pp.2413–2436. doi: 10.1002/ps.5355.

Matos, P.S. et al., 2020. Linkages among soil properties and litter quality in agroforestry systems of Southeastern Brazil. *Sustainability (Switzerland)*, 12(22), pp.1–22. doi: 10.3390/su12229752.

McGrath, D.A. et al., 2000. Nitrogen and phosphorus cycling in an Amazonian agroforest eight years following forest conversion. *Ecological Applications*, 10(6), pp.1633–1647. doi: 10.1890/1051-0761(2000)010[1633:NAPCIA]2.0.CO;2.

Mehta, N. et al., 2013. Changes in litter decomposition and soil organic carbon in a reforested tropical deciduous cover (India). *Ecological Research*, 28(2), pp.239–248. doi: 10.1007/s11284-012-1011-z.

Muoghalu, J.I. & Odiwe, A.I., 2011. Litter production and decomposition in cacao (theobroma cacao) and kolanut (Cola nitida) plantations. *Ecotropica*, 17(1), pp.79–90.

Mutshekwa, T. et al., 2020. Nutrient release dynamics associated with native and invasive leaf litter decomposition: A mesocosm experiment. *Water (Switzerland)*, 12(9), pp.1–12. doi: 10.3390/W12092350.

Noguchi, H. & Takami, Y., 2015. Allelopathic activity and allelopathic substance in jackfruit leaves. *Journal of Tropical Forest Science*, 27(2), pp.277–281.

Novara, A. et al., 2015. Litter contribution to soil organic carbon in the processes of agriculture abandon. *Solid Earth*, 6(2), pp.425–432. doi: 10.5194/se-6-425-2015.

Piza, P.A., Suárez, J.C. & Andrade, H.J., 2021. Litter decomposition and nutrient release in different land use located in Valle del Cauca (Colombia). *Agroforestry Systems*, 95(2), pp.257–267. doi: 10.1007/s10457-020-00583-6.

Ramesh, T. et al., 2019. Soil organic carbon dynamics: Impact of land use changes and management practices: A review. *Advances in Agronomy*, 156 (January 2021), pp.1–107. doi: 10.1016/bs.agron.2019.02.001.

Rangel-Mendoza, J.A. & Silva-Parra, A., 2020. Agroforestry systems of Theobroma cacao L. affects soil and leaf litter quality. *Colombia Forestal*, 23(2), pp.75–88. doi: 10.14483/2256201X.16123.

Riedel, J. et al., 2019. Effects of rehabilitation pruning and agroforestry on cacao tree development and yield in an older full-sun plantation. *Experimental Agriculture*, 55(6), pp.849–865. doi: 10.1017/S0014479718000431.

Sahid, I. et al., 2017. Quantification and herbicidal activity of mimosine from Leucaena leucocephala (Lam.) de Wit. *Transactions on Science and Technology*, *4*(2), pp.62–67. Available at: https://www.academia.edu/download/54309884/4x2x62x67.pdf.

Sanz, M.J. et al., 2017. *Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation*. *A Report of the Science-Policy Interface*., Bonn, Germany: United Nations Convention to Combat Desertification (UNCCD). Available at: https://www.unccd.int/sites/default/files/documents/2017-09/UNCCD_Report_SLM_web_v2.pdf.

Saputra, D.D. et al., 2020. Can cocoa agroforestry restore degraded soil structure following conversion from forest to agricultural use? *Agroforestry Systems*, 94(6), pp.2261–2276. doi: 10.1007/s10457-020-00548-9.

Sauvadet, M. et al., 2020. Cocoa agroforest multifunctionality and soil fertility explained by shade tree litter traits. *Journal of Applied Ecology*, 57(3), pp.476–487. doi: 10.1111/1365-2664.13560.

Schaad, N. & Fromm, I., 2018. Sustainable Cocoa Production Program (SCPP): Analysis of cocoa beans processing and quality in post-harvest in South East Sulawesi in Indonesia. *Asia Pacific Journal of Sustainable Agriculture Food and Energy*, 6(1), pp.1–6. doi: 10.36782/apjsafe.v6i1.1788.

Shaxson, F. & Barber, R., 2003. Optimizing soil moisture for plant production. *FAO Soil Bulletin 76*, p.126.

Singh, H., Batish, D. & Kohli, R., 1999. Autotoxicity: Concept, organisms, and ecological significance. *Critical Reviews in Plant Sciences*, 18(6), pp.757–772. doi: 10.1080/07352689991309478.

Singh, N.R. et al., 2019. Seasonal Dynamics of Litter Accumulation in Agroforestry Systems of Navsari District, Gujarat. *Climate Change and Environmental Sustainability*, 7(2), p.151. doi: 10.5958/2320-642x.2019.00020.6.

Singhal, V. et al., 2019. Leaf litter production and decomposition dynamics in four agroforestry tree species of western Himalayas. *Journal of Pharmacognosy and Phytochemistry*, SP1, pp.198–201.

Suárez, L.R. et al., 2021. Cacao agroforestry systems improve soil fertility: Comparison of soil properties between forest, cacao agroforestry systems, and pasture in the Colombian Amazon. *Agriculture, Ecosystems & Environment*, 314(April 2020), p.107349. doi: 10.1016/j.agee.2021.107349.

Takemura, T. et al., 2013. Discovery of coumarin as the predominant allelochemical in Guricidia sepium. *Journal of Tropical Forest Science*, 25(2), pp.268–272.

Weston, L.A., Ryan, P.R. & Watt, M., 2012. Mechanisms for cellular transport and release of allelochemicals from plant roots into the rhizosphere. *Journal of Experimental Botany*, 63(9), pp.3445–3454. doi: 10.1093/jxb/ers054.

Witjaksono, J. & Asmin, 2016. Cocoa Farming System in Indonesia and Its Sustainability Under Climate Change. *Agriculture, Forestry and Fisheries*, 5(5), p.170. doi: 10.11648/j.aff.20160505.15.

Xie, T., Shan, L. & Su, P., 2020. Drought conditions alter litter decomposition and nutrient release of litter types in an agroforestry system of China. *Ecology and Evolution*, 10(15), pp.8018–8029. doi: 10.1002/ece3.6264.

Zhang, X. et al., 2015. Allelopathic effects of decomposed leaf litter from intercropped trees on rape. *Turkish Journal of Agriculture and Forestry*, 39(6), pp.898–908. doi: 10.3906/tar-1406-88.

Zhang, Z. et al., 2021. Effect of allelopathy on plant performance: a meta-analysis. *Ecology Letters*, 24(2), pp.348–362. doi: 10.1111/ele.13627.

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