Towards Sustainable Agroforestry Management: Harnessing the Nutritional Soil Value through Cocoa Mix Waste

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Abstract

Climate change and environmental degradation have contributed in compromising the soil nutrient integrity of cocoa farmlands, yet sustainable nutrient recycling innovation in cocoa waste management has received less research attention. Utilizing experimentation methodology in an agroforestry system composed of cocoa (*Theobroma cacao L.*) and a Nitrogen-fixing Gliricidia sepium (*Jacq. Kunth ex Walp.*), the study examines how the soil nutritional level of farmland can be enhanced. The study confirms the proposition that the rate of decomposition and nutrients release from an innovative mixed waste sample (60% cocoa waste and 40% gliricidia waste in this case) is significantly higher in comparison with the traditional cocoa waste only sample. The results further established that innovative mixed waste sample had a faster decomposition rate (no biomass left at 216 days after laying) as compared to traditional cocoa waste which fully decomposed at 277 days after laying. A difference of 51 days after laying justifies the waste mixture decomposition as a sustainable nutrient recycling innovation within cocoa agroforestry waste management context. These results have implications for agroforestry waste management, soil nutrient recycling and cocoa industry performance.

Key Words: Cocoa Industry, Farmlands, Soil Nutrients, Innovation in Agroforestry

1.0. Introduction

Towards the attainment of the sustainable development goals (SDGs) 1 (No Poverty), 13 (Climate Action) and 15 (Life on Land), Ghana will need to increase its agricultural productivity from the current less than 4% to about 6% per year, without harming the environment (Jackson and Acharya, 2007, Al-Hassan et al., 2008). The cocoa industry is a critical sector for sustainable development in all cocoa-growing developing countries. In Ghana, it is a major source of foreign exchange and employs 25-30% of the country's population. Such a major industry is however saddled with many challenges, particularly the loss of soil suitable for enhanced cocoa production (Läderach *et al.*, 2013) due to unsustainable production practices and desertification (Asante and Amuakwa-Mensah, 2015). The net effects of these problems is the prevalent low average yields (350 kg/ha) compared to other producing countries with similar agro-climatic conditions such as Ivory Coast and Malaysia, whose output range between 800-1000kg/ha (Dormon *et al.,* 2004). Without urgent intervention to restore soil fertility problems, cocoa farms yields are expected to further decline (CRIG and WCF, 2017). Consequently, cocoa plantation soil nutrients conservation, recycling, management and innovation have become a critical feature for consideration by cocoa sector stakeholders.

Previous studies have attempted to tackle this problem by encouraging farmers to prune legume biomass and using it as green manure (Kaba and Abunyewa, 2019), assessing how much nutrients can be released from only the biomass of cocoa litter (Fontes et al., 2014), nutrients recycling under cocoa plantation (Dawoe et al., 2010) and intercropping shade trees with cocoa as a source of direct transfer of nutrients (Isaac et al. 2009; Kaba et al., 2019ab). Despite some nutritional contributions that can be achieved by these methods, there are practical limitations such as the high amount of legume biomass required as green manure, low nutrients quantity in non-legume shade trees and slow rate of decomposition of cocoa waste due to their high carbon, lignin, polyphenol and cellulose concentrations.

Bearing in mind these limitations and prevailing concerns, this study builds further on these previous studies and attempts to advance the current state-of-the-art knowledge (Decomposition Innovation; hereafter -DI) in the field of soil nutrient recycling and environmental sustainability by assessing the speed (rate) of decomposition and release of some micronutrients among different residues commonly found in cocoa agroforestry systems, with emphasis on integrating a high nitrogen, low carbon and rapid decomposing legume biomass.

The amounts of cocoa Agroforestry Residues in Ghana and most West Africa countries is between 5 and 10 t/ha/year of dry matter. This residue contains significant amount of nutrients which can be made available for cocoa uptake after decomposition (Hartemink, 2005; Dawoe *et al.,* 2010; Fontes *et al.,* 2014). It is therefore not surprising that for the majority of cocoa farmers, fertility of soils under cocoa plantations is maintained through the recycling of nutrients through residue decomposition (Lal, 2008; ISSER, 2004; Dawoe *et al.*, 2010). In addition, residues (biomass) decomposition could add other valuable micronutrients, such as Manganese, Calcium, Boron and Magnesium to the soil, which have received less attention in cocoa nutrients research, for the maintenance of the cocoa plantation.

We set out to test the proposition that when residues from two or more plant species are mixed, the rate of decomposition and nutrients release of the waste mixture will be faster and higher than the decomposition rates and nutrients release of each plant species separately (Otsing et a., 2018; Liu et al., 2020; Porre et al., 2020).

To achieve these objectives the rest of the paper is structured as follows: firstly, we review the extant literature on cocoa agroforestry systems and sustainable soil nutrient cycle. Secondly, we described the method used, which entails the research setting, description of the experimental site, the decomposition innovation (DI), assessment of the speed (rate) of decomposition and release of nutrients. Thirdly, we present the results of the study.

Finally, we discuss the results and their implications for agroforestry waste management, soil nutrient recycling and cocoa industry performance.

2.0. Cocoa Intercropping Systems and Sustainable Soil Nutrient Cycle

The importance of leguminous trees in enhancing the nutritional level of croplands is highlighted by a study by Bashan et al. (2012) who reported on the restoration of eroded soil in the Sonoran Desert. In fact, within the specific case of cocoa production, Asante (2002) and Asare (2005) both reported that the integration of leguminous species in intercropping systems is a key environmentally-friendly and sustainable strategy in solving the critical nitrogen needs in cocoa production. Considered as part of an agroforestry system, the leguminous species provide shade for the cocoa crop as well as improve soil fertility and in particular increase the nitrogen (N) level. Leguminous shade trees that have the ability to fix atmospheric nitrogen (N_2) usually form symbiotic associations with rhizobia in their root nodules (Kinkema *et al.*, 2006). This biological nitrogen (BN) is unlimited, environment-friendly and a sustainable source of N and can complement or replace mineral fertilizer inputs (Isaac *et al.*, 2007b; Tscharntke *et al.*, 2011). The BN is also used directly by the plant and is less susceptible to volatilization, denitrification and leaching (Garg and Geetanjali, 2007; Kaba et al., 2019b). In addition to N, cocoa plants can benefit from other nutrients through the internal nutrient recycling of waste and vegetative pruning of both the cocoa and the N-fixing trees during decomposition. A well-known intercropping plant is Gliricidia - a multipurpose leguminous plant and can obtain up to 44-58 % of its nitrogen from N_2 fixation (Kaba et al., 2019a; Liyanage et al., 1994). Gliricidia is usually used to provide shade to cocoa and other tree crops due to its resistance to the defoliating psyllid (*Heterosphylla cubana*). In addition, it has the ability to produce high biomass and good green manure. The green manure is rich in nutrients with low concentrations of lignin and active polyphenol and decomposes in a short time (Vanlauwe, 1996; Anhar, 2005).

N released from Gliricidia biomass decomposition may reach 20-47 kg N ha^{-1} yr^{-1} (Nygren et al., 2000; Anhar, 2005). However, Gliricidia N_2 fixation, N concentration and quantity of biomass produced vary in different regions and locations (Anhar, 2005; Marroquin et al., 2005).

In spite of Nitrogen releasing potential from Gliricidia biomass decomposition under cocoa agroforestry system, the pace of the traditional nutrient recycling of cocoa waste and vegetative pruning of both cocoa and the N-fixing trees during decomposition is slow. Juxtaposing the slow rate of decomposition to promote soil nutrient recovery against the critical nutrient deficit pertaining in the cocoa industry presently, highlights a further justification to explore decomposition innovation which holds a massive potential (ISSER, 2004; Dawoe et al., 2010; Vásquez et al., 2019) but has received limited research attention and application in cocoa agroforestry systems.

3.0. Methods

3.1. Research Setting

In cocoa systems where legume trees are intercrop, large amounts of nutrients regularly reach the soil surface through abscised leaves or pruned material (Brunetto *et al.,* 2011). Legume species contain large amounts of N deriving from the atmosphere, so when they are pruned this atmospheric N might eventually be available for cocoa trees. The waste left on top of the soil undergoes decomposition and represent a major source of organic matter and nutrients in the ecosystem (Triadiati *et al.,* 2011; Vellend *et al.,* 2011; Veloso et al., 2020). Therefore, sustainable management of mineral nutrition in tree plantations should aim at exploring the use of these internal sources of nutrients to reduce the need for inorganic chemical fertilizers (Isaac *et al.*, 2007b; Brunetto *et al.*, 2011; Tscharntke *et al.*, 2011).

In Ghana, about 1.6 million hectares of land are under cocoa cultivation, but only 20% of this area receive mineral fertilizer application and only 17% of cocoa farmers apply any type of inorganic fertilizer (Gockowski and Sonwa 2011; IFDC, 2012; CRIG and WCF, 2017).

This is because mineral fertilizers are often inaccessible and unaffordable for smallholder farmers, who constitute the majority of cocoa farmers in Ghana (Opoku-Ameyaw *et al.*, 2012; Nunoo *et al.*, 2013).

These are farmers involved in farming a small piece of land (<5 acre) with farm operations largely managed by family labour and cocoa production serves as a primary source of direct income (70–100% of their yearly income) and livelihood (Nyambo et al., 2019; Ameyaw et al., 2018). Thus, for the majority of cocoa farmers in Ghana, fertility of soils under cocoa plantations is maintained through the recycling of nutrients through leaf biomass and decomposition of leaf litter (ISSER, 2004; Dawoe *et al.*, 2010). The majority of cocoa farmers in the study area practice cocoa agroforestry system, where multipurpose shade trees are integrated into their cocoa farms (Kaba and Abunyewa, 2019). Thus, such soil fertility management practice could further improve when N-fixing legume trees are intercropped with cocoa due to the extra amount of fixed N and other nutrients present in their biomass (Hartemink 2005; Anhar, 2005; Isaac *et al.,* 2007).

In this study, we explored the effect of mixing legume biomass (from Gliricidia) to cocoa litter on decomposition and micronutrients release. Gliricidia (*Gliricidia sepium* (Jacq.) Kunth ex Walp is a medium size legume tree that fixes N and it is capable of producing high quantity of biomass within a short period after pruning (Liyanage *et al.,* 1994; Subramanian *et al.,* 2005; Kaba and Abunyewa, 2019). The choice of gliricidia in this study is because it is currently the most commonly planted shade tree for cocoa in Ghana and the leaf litter production in cocoa ecosystems ranges from 5-20 t DW ha^{-1} $year^{-1}$ (Anim-Kwapong, 2003; Srinivasa Rao *et al.,* 2011). Cocoa farmers allow this leaf litter (waste residue) on the soil surface of their farms to undergo natural decomposition to serve as source of nutrients for the cocoa tree (Dawoe *et al.*, 2010).

3.2. Experimental Site

The study was conducted at the experimental farm of the Faculty of Renewable Natural Resource (FRNR), Kwame Nkrumah University of Science and Technology (KNUST), Ghana. The site is located at Latitude 06 43^0 N and Longitude 01 36^0 W (Figure 1).

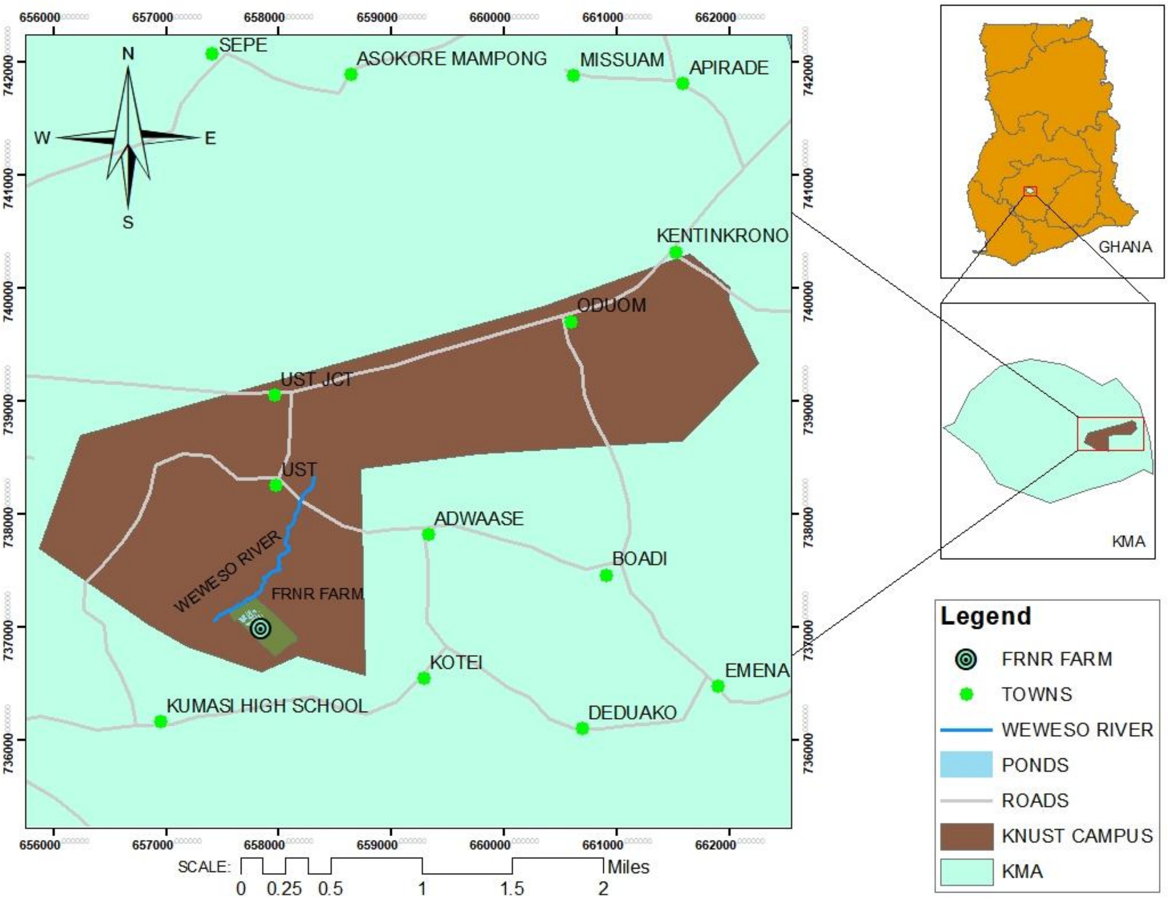

Figure 1 Map of Ghana showing the study site (FRNR Farm) at KNUST

The area falls within the semi-deciduous forest zone of Ghana and is characterized by a bimodal rainfall pattern (Partey *et al.*, 2011). The major rainy season starts from March to July while the minor season starts from late August to November. The annual rainfall of the area ranges between 500 mm-1250 mm.

The area has a mean annual temperature of 26.6 ^{O}C, annual humidity of 67.6 % and the soil type is Ferric Acrisol. The soil before the start of the study had 0.09% N, 1.3% organic carbon and pH of 5.2. The gliricidia trees in the plantation are intercropped in rows with the cocoa. The plantation received no external nutrient supply with overgrown gliricidia biomass usually top pruned and the biomass left on the soil surface.

3.3. Description of Decomposition Innovation (DI)

The conventional method of waste/residue decomposition by farmers is to allow the residues on the surface of the farm to naturally decay. However, this approach is slow and does not add the required amounts of nutrients to the soil because of the high carbon (C), lignin and polyphenol level of cocoa waste, their low nitrogen (N) concentration, and the high Carbon: Nitrogen ratio (N-unkyer, 2005; Dawoe *et al.*, 2010). However, there is evidence of the prospect for appropriate selection of residues and combining them in their right proportions, to enable farmers speed up the decomposition of waste/residues on their farms and such decomposed materials will contain higher concentrations of nutrients than the conventional decomposed residues (Berger and Berger, 2014, Xiaogai et al., 2013, Zhang et al., 2016).

To test this innovation, we mimic waste decomposition in cocoa intercropping system where gliricidia (a legume N fixing tree) is present as an intercrop. In this study we used three biomass types in our experiment: 1) Cocoa residue/biomass 2) gliricidia (above 6 years old trees) pruning materials and 3) a Mixed biomass (60 % cocoa biomass and 40 % gliricidia pruning). Our choice of the biomass ratio is to mimic litter production under farmers condition where cocoa leaves constitute about 60% in litterfall under cocoa agroforestry systems (Isaac, 2003)

Cocoa residues was collected using a modified method of N-unkyer (2005) and Jose et al. (2000), where twenty litter traps were randomly placed in the central part of a 1-hactere cocoa-Gliricidia stand at the Faculty of Renewable Natural Resources (FRNR farm). Each trap was made of a 1 mm nylon mesh fitted to stakes fixed 1m x 1m in the ground, ensuring that the base of each net was raised at least 1 m from the ground. Each trap was placed between two neighbouring cocoa trees and at a distance ranging from 5–10 m from the nearest shade tree. The traps were emptied every 2-3 weeks beginning from January to the end of April. However, the gliricidia pruning was obtained by pruning the base of the current growth shoots of 6 selected gliricidia trees in April.

1 mm mesh nylon net was used to design a mesh bag/litterbag (hereafter called "Experimental bag") sewn into 30 cm x 25 cm according to the recommendation of Harmon et al. (1999) and Magill and Aber, (1998). This technique makes it possible to recover the residual biomass even after the material has undergone some decomposition (Mugendi et al., 1999).

The use of Experimental bag allows entry to most arthropods and small litter fractions which normally mix with leaf litter, the nutrient release from such experiment is assumed to be similar to actual conditions on the forest floor (Gosz et al., 1973).

In total, 63 Experimental bags were sewn (21 Experimental bags for each residue/biomass). The equivalent of 150g (D.W) of each residue/biomass was placed into each Experimental bag. On 10th April, a total of 9 cocoa trees were selected (3 trees for each residue/biomass). Under each tree, we laid (at 0-15cm soil depth) seven Experimental bags of each residue/biomass (7 Experimental bags/tree per residue/biomass).

3.4. Assessment of the speed (rate) of decomposition and release of some micronutrients of residues from the DI

At 42 days after laying (DAL), we randomly sampled three Experimental bags of each residue/biomass under each tree. This was repeated during each sampling time at 83, 126, 216 and 277 DAL. During each sampling time, the decomposing residue/biomass were carefully removed from their Experimental bags and cleaned of all soil and plant debris; whenever necessary, the recovered Experimental bags were rinsed in water for 1-2 minutes to remove soil particles. The dry weight of the remaining residue/biomass was recorded after oven-drying at 60°C for 72 hours to a constant mass. For the nutrient analyses, the dried residue/biomass was crushed through a 2mm sieve. Each sample was then milled into a homogenous powder, using a ball-and-capsule vibrating mill.

The carbon and N concentration of the samples was determined by encapsulating 2.0 - 2.5 mg of the milled material in a tin cup and analyzed using the Continuous flow isotopic ration mass spectrometer, EA-Flash 2000 ThermoFisher Scientific instrument. The Ca, Mg, Mn and B concentrations were determined by ICP-OES (according to the EPA Method 6010C–ICP-OES (EPA 2007) after microwave digestion with nitric acid according to EPA Method 3052 (EPA 1996).

4. 0. Result

4.1 Biomass decomposition pattern and change in Carbon

The analysis of the decomposition process has been made by assessing the biomass remaining, carbon (C) and nitrogen (N) in the Experimental bags. The Carbon: Nitrogen ratio of gliricidia pruning and mixed biomass reflected in the rate of biomass decomposition (Figure 2).

For example, the initial Carbon: Nitrogen ratio of gliricidia pruning, cocoa residue and mixed biomass was 11, 13 and 26 respectively. There was no quantifiable biomass deriving from gliricidia pruning after 126 days of decomposition, while the amount of cocoa residues recovered at 216 days of decomposition was significantly higher than that of mixed biomass (Figure 2). Only cocoa residues (about 10 % of the original amount) was recovered on the final day (277 days) of sampling. Generally, the decomposition followed a rather linear trend over time; with only gliricidia pruning showing a more rapid decomposition between day 83 and day 126 (Figure 2).

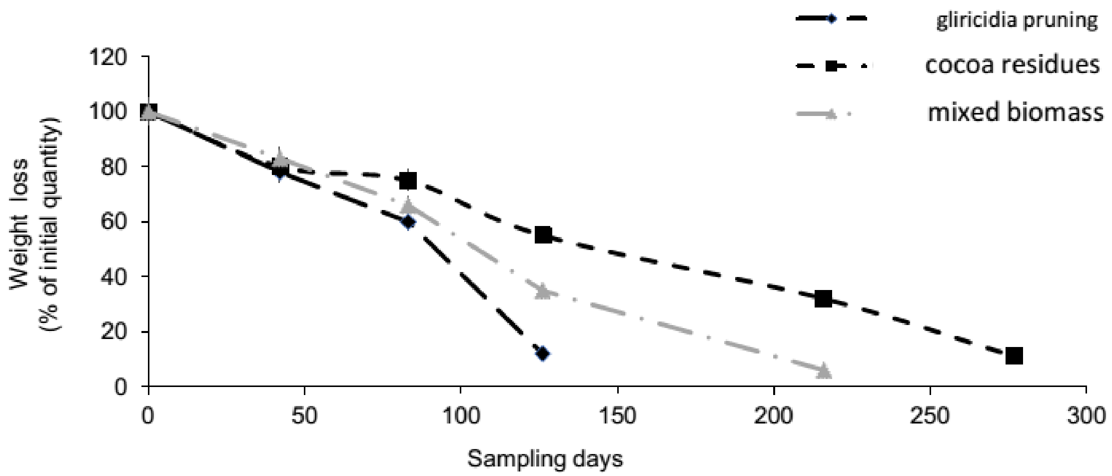

Figure 2 Percentage of the initial biomass (= 100%) remaining in the litter bags during the decomposition experiment (bars indicate standard errors)

The differences among residues/biomass as far as the change in the amounts of carbon is concerned reflected those in the biomass but were of lower intensity. For instance, in Figure 3, the initial amount of carbon in gliricidia pruning, mixed biomass and cocoa residues were 67.9 g, 66.3g and 61.0g per Experimental bag respectively, and this was significantly higher than the amount at the different stages of decomposition (Figure 3).

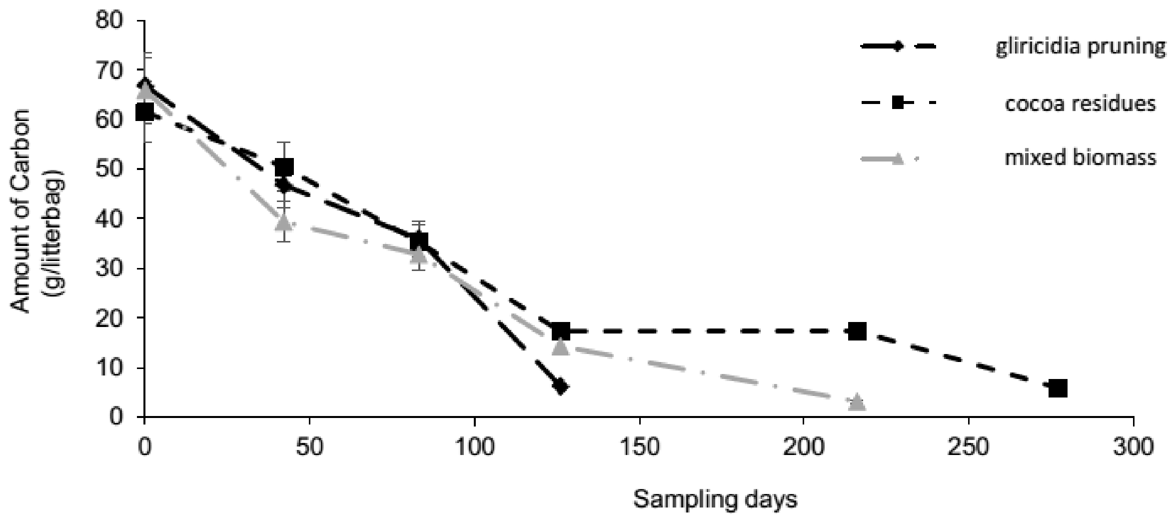

Figure 3 Amount (g) of the initial Carbon remaining in the litter bags during the decomposition experiment (bars indicate standard errors)

4.2 Pattern of nutrients release

The initial nutrients content varied among the residues/biomass. Gliricidia pruning showed higher initial content of micronutrients than cocoa residues and mixed biomass except for manganese (Mn). Magnesium (Mg) and calcium (Ca) at the initial stage and at 42 days were not significantly different in gliricidia pruning, but at 83 days 27% of the initial amount was lost, with 5% and 12 % remaining at 126 days for Mg and Ca respectively (Figure 4 to 5).

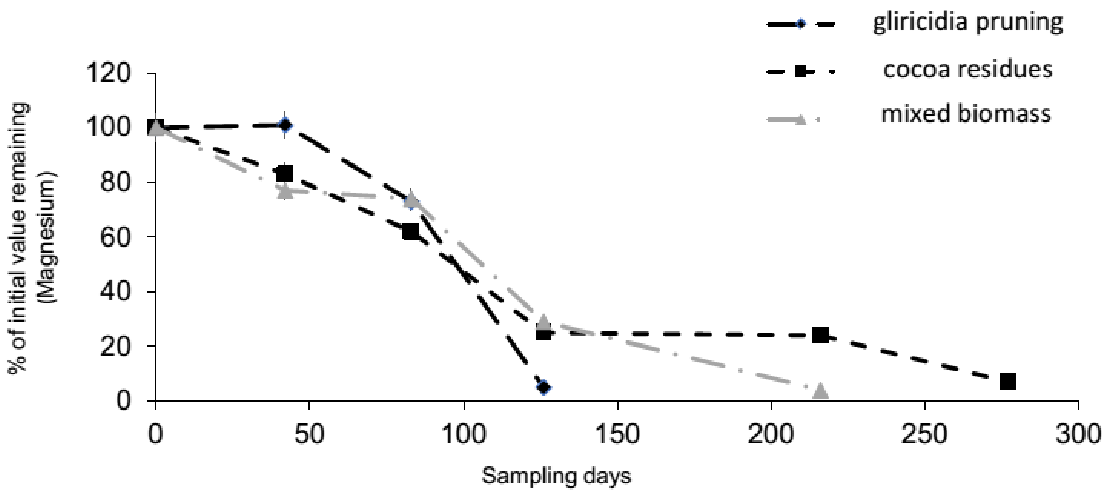

Figure 4 Percentage of the initial Magnesium (= 100%) remaining in the litter bags during the decomposition experiment (bars indicate standard errors).

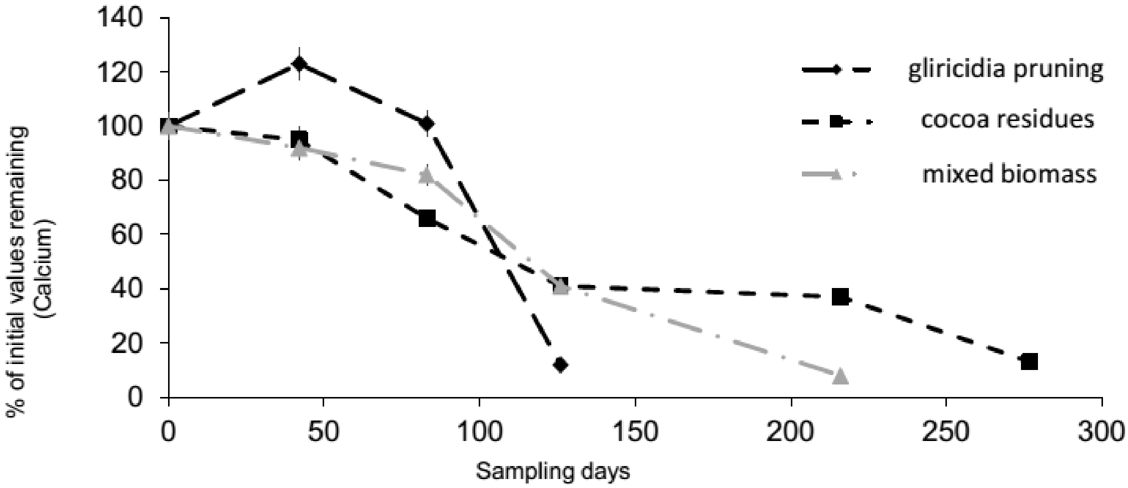

Figure 5 Percentage of the initial Calcium (= 100%) remaining in the litter bags during the decomposition experiment (bars indicate standard errors).

However, cocoa residues and mixed biomass showed a linear pattern of Mg and Ca release from the initial stage to the last day of decomposition. The release was however more rapid in mixed biomass than cocoa residues.

For example, cocoa residues lost an average of 18% of its initial amount of Mg at every stage of decomposition compared to 24% Mg and 22% Ca in mixed biomass (Figure 4 and 5).

Manganese (Mn) was however different, as it showed an increased trend from the initial stage to 43 days of decomposition (Figure 6). At 43 days, there was an increase of 45% of the initial amount of Mn in both gliricidia pruning and mixed biomass, while that of cocoa residues was 15%, this pattern changed after the 42 days, showing lower release in the subsequent days of decomposition (Figure 6).

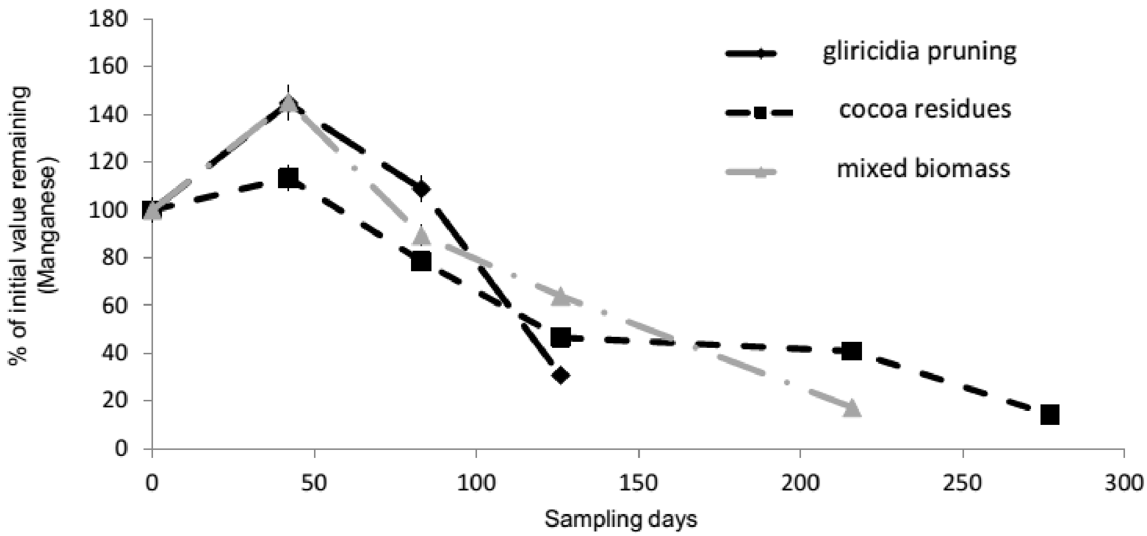

Figure 6 Percentage of the initial Manganese (= 100%) remaining in the litter bags during the decomposition experiment (bars indicate standard errors)

Generally, all the three residues/biomass showed a decreased in the amount of Boron (B) from the initial amount at every stage of decomposition except in cocoa residues at 42 days (Figure 7). On average, all the three residues lost 80% of their initial amount of Boron on their last days of decomposition (Figure 7).

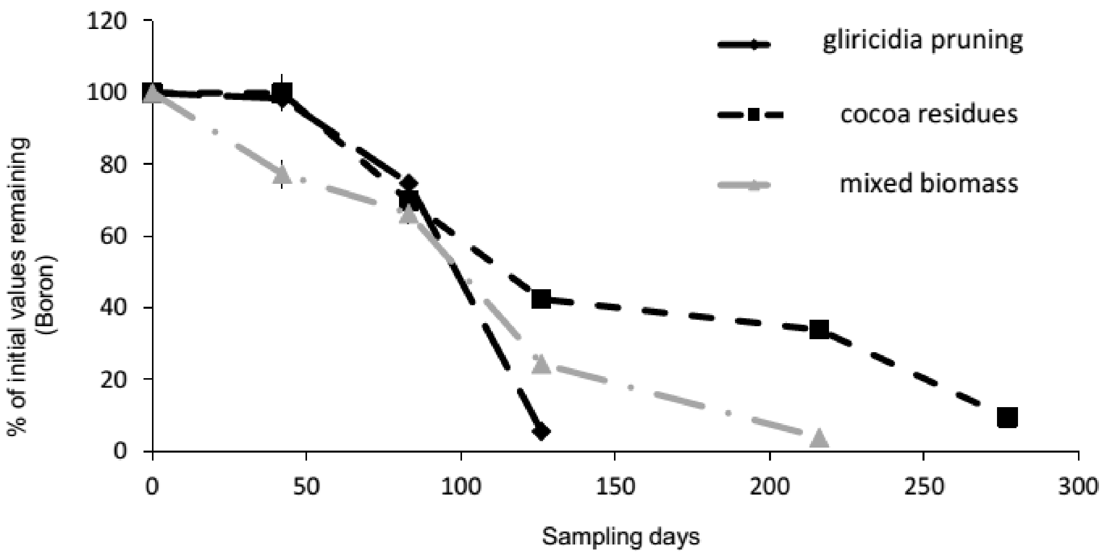

Figure 7 Percentage of the initial Boron (= 100%) remaining in the litter bags during the decomposition experiment (bars indicate standard errors)

5.0. Discussion

In an Agroforestry system the woody perennials take up large quantity of nutrients from the soil for their growth. Most of these nutrients are stored in their organs (e.g., roots, trunk branches and shoots) which are later pruned or abscised. Sustainable and environment-friendly management of soil fertility in tree plantations will require improving the use of nutrients residing in residues and wastes to reduce the need for external chemical fertilizers (Tartachnyk and Blanke, 2004; Pérez-Lomas et al., 2010; Brunetto *et al.*, 2011). It is therefore not surprising that farmers' conventional method of soil nutrient enrichment is the natural recycling (decomposition) of waste materials under cocoa plantation (ISSER, 2004; Dawoe *et al.*, 2010).

In the present study we provide an alternative decomposition innovation (DI) to help speed the decomposition and release of nutrients from the residues/waste produced in cocoa plantations, by assessing the nitrogen, biomass and the carbon (C) remaining.

The result of the DI experiment showed that the initial N, carbon and Carbon: Nitrogen ratio influenced the rate of decomposition and micronutrients release among the residues. The evidence is seen in the results on both gliricidia and mixed biomass which had higher N (average of 4%) concentration and lower Carbon: Nitrogen ratio (average of 16) and both decomposed and released over 90% of the micronutrients within 126 days while cocoa residues with 1.6 % N and Carbon: Nitrogen ratio of 26, took 277 days to decompose and release less than 90% of its nutrients. This pattern has been collaborated by earlier studies of decomposition of different plants biomass where biomass with > 2% N and Carbon: Nitrogen ratio of less than 20 often exhibited faster decomposition and nutrients release due to leaching of readily soluble substances and non-lignified carbohydrate (Schwendener *et al.,* 2005; Leblanc *et al.,* 2006).

In addition, the differences among the residues in the amounts of carbon (C) mirrored the speed of decomposition and nutrients release. For example, the initial amount of carbon in gliricidia pruning, mixed biomass and cocoa residues was 67.9g, 66.3g and 60.0g per Experimental bag respectively, consequently, at 126 days of decomposition, there was no quantifiable biomass deriving from gliricidia pruning, and mixed biomass had also lost over 90% of its initial weight, while cocoa residues took 277 days to decompose and release 90% of its initial weight and nutrients.

More importantly, we found the additive effect of mixing gliricidia pruning with cocoa residues (i.e. mixed biomass) as decomposition in mixed biomass increased relative to those expected on the basis of the rates obtained from only cocoa residues (Figure 2). This provides a greater and better opportunity for cocoa farmers to convert the large quantity of cocoa waste on their farms into nutrients-enriched organic manure within a shorter period of time. Additionally, such improved innovation is much efficient as both decomposition and nutrients release occur in situ, in close proximity to the cocoa trees. This observation is divergent to previous view that when leaves from two or more plant species are mixed, decomposition rates of the litter mixture may not correspond to that estimated from the decomposition rates of each plant species alone due to retarding and antagonistic effects among species composing the litter mixture (Gartner and Cardon 2004; Pérez Harguindeguy et al. 2008). We can attribute the differences in the above position with the current result to the type of plant species composing the mixture, since we used biomass of a legume N fixing tree (Gliricidia) which has higher N and lower C concentration. Our finding however confirms suggestions by Wang *et al*. (2009), Song et al. (2010) and Jacob et al. (2010) that decomposition of foliar litter of a given species could be enhanced when foliar litter of other species is present due to synergistic effects. Hättenschwiler et al. (2005) earlier attributed such synergistic effects to four complexes of mechanisms: (1) nutrient transfer where preferential decomposition of high-quality litter increases nutrient availability and induces nutrient transfer to the low quality litter that, in turn, will be decomposed more rapidly (2) stimulating effects of specific litter compounds (3) improved microclimatic conditions; or (4) interactions across trophic levels of decomposers; where the population density at lower trophic levels are regulated by species at higher trophic levels, a phenomenon which depend on the diversity of litter species.

The nutrients released during decomposition also differed among the biomass types. In line with the findings of Brunetto *et al.* (2011), the release of Mg and Ca in our study was small and fairly stable in all the biomass types used (Figure 4 and 5). However, in previous study by Zaharah and Bah, (1999), a relatively faster release of Mg and Ca (e.g., over 75% of the total Ca content was released within 6 days, compared to 70% of Mg in 23 days) was recorded in gliricidia pruning. Manganese (Mn) showed an increased trend from the initial stage to 43 days of decomposition. Ber et al. (2007) explained that litter with high Mn concentrations influences mass loss rates in decomposition, and this fluctuates depending on species as the relationship is stronger with species that take up high amounts of Mn. Even though we did not make analyses for lignin content, Dawoe et al. (2010) found that lignin and polyphenols were predominant in cocoa residues and in leaf litterfall in cocoa agroforestry system. This could have explained the fact that with greater lignin decay more Mn was required.

6.0. Conclusion

In the present study we have provided an alternative decomposition innovation (DI) to help speed the decomposition and release of nutrients from the large residues/waste produced in cocoa plantations. We established that the initial N, carbon and Carbon: Nitrogen ratio influenced the rate of decomposition and micronutrients release among the residues. Gliricidia pruning had fastest rate of decomposition followed by mixed biomass, while cocoa residues was very slow in decomposing and releasing its nutrients.

The results established that there is an additive effect of mixing (40%) nitrogen enriched biomass (mixed biomass) with cocoa residue and this results in increased decomposition rates and nutrients release relative to those expected on the basis of the rates obtained from only cocoa residues.

This finding provides a better opportunity for cocoa farmers to convert the large quantity of cocoa waste on their farms into nutrients-enriched organic manure within a shorter period of time. Additionally, since the DI allows decomposition to occur in situ, the nutrients are released in close proximity to the cocoa trees.

7.0 Implications for Agroforestry Waste Management, Soil Nutrient Recycling and Cocoa Industry Performance

Generally, agroforestry waste management seeks to address problems for waste disposal and the negative impacts on the environment as a result of the disposal methods (Béliveau et al., 2020). In the particular of Ghana's Cocoa agroforestry system, an innovative approach to agroforestry management, which supports the problems of waste would have direct influences on sustainable crop production, improve productivity and the much-needed foreign exchange earnings. Undoubtedly, the cocoa industry is a source of livelihood for millions of farmers but waste accruing from its cultivation is a major concern (de Araújo Veloso et al., 2020) and the leading global producers (Cote d'Ivoire and Ghana) that accounts for 63% of the global cocoa beans production in 2016/17 (ICCO 2017) have a lot of cocoa waste to manage. It is important to recount that just ten percent (10%) of the total cocoa fruit weight is utilized for cocoa beans products (Rojo-Poveda, et al., 2020) as the remaining ninety percent (90%) is left on farmlands as waste. Tackling cocoa agroforestry waste in Ghana has featured in many policy documents by the COCOBOD but very limited success has been achieved in practice (Monastyrnaya, 2016). The outcome of a ten-year study (1993 – 2003) by the Cocoa Research Institute of Ghana (CRIG) found that it was commercially feasible to transform traditional cocoa waste products into economically viable value-added products (see, Adomako, 2006). Indeed, Obuobisa-Darko (2015) identified potential by-products such as pectin, alcohol and alcoholic beverages, animal feed, jelly, soap and cosmetics among others.

There are about five cocoa waste companies, licensed by COCOBOD, that purchase cocoa waste in the form of cocoa shells, husks and cocoa skin from domestic cocoa processors for export (Monastyrnaya, 2016). This means the bulk of cocoa wastes including intercropped biomass are discarded under cocoa plantations to be slowly decomposed naturally, mainly under the influence of prevailing temperature and humidity (Dawoe, 2010). Tompson (2008) has earlier highlighted Ghana's general waste management challenge including that emanating from the cocoa industry. Thus, the news of a successful study to use cocoa husks as feedstock to produce clean biofuel in Ghana (Lowry, 2019) was well received by stakeholders with optimism to be able to manage the growing cocoa agroforestry waste.

Insight from the experimental analysis in this study establishes that the innovative use of mixed waste in cocoa production can result in the natural enhancement of soil nutrition and consequently on cocoa production. Drawing from Innovation Theory (Sumberg, 2005), even as applied to agricultural systems, the following factors ("Innovation Itself", "Communication Channels", "Timeframe" and "Stakeholders") are identified as key drivers to ensuring that agro innovation such as enhanced agroforestry residues decomposition becomes a standard practice in the cocoa growing industry. A facilitation of this innovation process in practice would require that within a specified working timeframe, key emerging stakeholder in the cocoa industry (in Ghana these stakeholders include (Yamoah et al., 2020): Ghana Cocoa Board (COCOBOD, Cocoa Farmers, Service providers (Cocoa extension services), relevant NGOs and Civil Society Organizations, Cocoa Cooperatives (eg. Kuapa) and Farmer Groups, etc) should be engaged and outreach programmes on "Enhanced Agroforestry Residues Decomposition Innovation" put in place to communicate, train and upscale it within the industry.

Like all innovation programmes, a wider implication is the added co-benefits. Whiles the enhancement of soil nutrition and increased in cocoa production would directly benefit from an agroforestry residues decomposition innovation programme, co-benefits such as mitigation against climate change caused by the traditional burning of agroforestry waste and enhanced biodiversity conservation, etc can also be achieved.

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