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The Potential and Coupling Effect of Compost and *Mucuna* for Quarry Site Restoration: A Study at the YongwaLimestone Quarry in Ghana

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Abstract This study evaluated the potential and coupling effect of compost and *Mucuna pruriens* for soil fertility improvement of degraded soil at the Yongwa Limestone Quarry site in Ghana. Compost was produced from a mixture of pig manure and cassava wastes collected from nearby communities, applying simple open windrow technique. The compost was used to cultivate *Mucuna*, a leguminous climbing plant on degraded plot at the Quarry site. The experimental design included a second plot where *Mucuna* was planted without compost and a control plot without any intervention. The growth rate of the *Mucuna* on the plot with compost was about twice its growth rate on the plot without compost. Plot treatment was observed over a period of three months. The control plot with no intervention attracted only one kind of plant species, but planting of *Mucuna* without compost attracted five different colonising plant species. When the *Mucuna* was planted with compost amendment, eleven different plant species colonized on the plot, which also showed relatively elevated contents of nitrogen, phosphorous and organic carbon. The increments in the respective soil nutrients were significant. It created a somewhat fertile ground for dispersed seeds of early colonizers to flourish. Another hypothesis was the possibility of broader *Mucuna* leaves to offer limited but useful protection for shade loving seeds to germinate. The colonizers thrived in close proximity to well-growing *Mucuna* plants. A symbiotic association was subsequently suggested in which rapidly growing colonisersprovided support for the *Mucuna* to climb, in return for the benefits these new colonies received from the *Mucuna*. The potential of the compost/*Mucuna* intervention in revitalizing degraded land could be applied during decommissioning work to restore quarry or mine sites. The concept could also be extended to local farming communities to help improve soil fertility for crop cultivation. This would limit the dependence on costly chemical fertilizers, while encouraging the production of organic crops.

Keywords: *composting, Ghana, leguminous plant, quarrying, revegetation, soil fertility*

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1. Introduction

Quarrying is a very important economic activity for the extraction of various kinds of gravels that are utilised in the construction industry. During quarrying, fertile top soils are lost, while various chemicals otherwise locked up or buried in the earth’s crust are extruded to the surface and inadvertently released into the ecosystem. Quarry activities, thus, cause significant changes to the physico-chemical properties of the soil and degrades the soil’s potential to support plant growth [1]. For this reason, a key consideration in land reclamation of a quarry site is to restore the soil properties to a level that would ensure re-vegetation. Given the loss of topsoil during quarry activities, it is important to amend the soil with organic matter to help re-establish microbial communities and initiate mineralization processes in the soil.

An innovative way to achieve this is to apply compost [2]. The amendment process is relatively simple, environmentally friendly, cheap and potentially effective for most degraded soils. Compost has numerous benefits; it improves soil properties, helps to maintain stable soil moisture, prevents soil-borne diseases, acts as a buffer for gradual release of plant nutrients, and ensures that plant nutrients are not easily lost through runoffs [3]. There is also evidence to suggest that applying compost may immobilize contaminants in soil and limit their bioavailability [4]. Another way of boosting soil fertility during reclamation activity is by planting leguminous species, considering that they contain symbiotic nitrogen fixing bacteria in their root region, which helps to fix atmospheric nitrogen into soil nitrogen [5,6].

Thus, individually, both compost and leguminous plants provide unique benefits when applied for land reclamation purposes. In this study, we explored the potential of combining these two approaches to accelerate re-vegetation at the Yongwa Quarry site in Ghana. The *Mucuna pruriens*, a leguminous climbing plant, was applied in combination with compost and investigated from the perspective ofre-vegetation and site colonisation for the first time. The *M. pruriens* is an annual shrub and its foliage is known to degrade quite fast, enriching the surrounding soil with nutrients. It produces pod bearing seeds that are easily released when the pods are dry. This phenomenon would naturally propagate the *Mucuna*, initiating new cycles of growth with the benefits of soil nutrient enrichment and restoration. The concept is one that could be applied to initiate re-vegetation during decommissioning work to restore a quarry site.

The compost applied in this study was produced from organic wastes sourced from the immediate villages surrounding the Yongwa Quarry. As farming communities, the villages surrounding the Yongwa Quarry in Ghana generate a lot of putrescible organic wastes. Some of these wastes include the peels of plantain, cassava and various fruits, corncob, wastes from livestock such as fowl, goat, sheep, pig, etc. These wastes when left unattended attract rodents that are destructive to both farm produce and domestic properties. It is therefore of immense benefit to the community that the organic waste generated was collected and composted, much as it is of benefit to the Quarry company that the compost could be applied for reclamation work. It ensures a win-win situation for both company and community.

The aim of this study was to assess the effectiveness of using a combination of compost and leguminous creeping plant (*Mucuna pruriens*) for soil amendment and re-vegetation of degraded quarry site.The study sought to demonstrate that a combined compost/*Mucuna* intervention has the potential to initiate and quicken re-vegetation exercise at a degraded quarry site, while promoting richness in the diversity of plant species that colonize on the site.

2. Methodology

2.1. Study Area

The study was conducted at the Yongwa Limestone Quarry site in Ghana. The Yongwa Quarry is located near Oterkpolu (latitude: 6° 33' 00'' / longitude: 0° 04' 40'') in the Eastern Region of Ghana (Figure 1). The Yongwa Quarry is operated by Ghacem Ghana Limited, a subsidiary of HeldelbergCement Group. The limestone extracted from the Yongwa Quarry is used by Ghacem to produce cement in Ghana. The people of Oterkpoluand nearby villages that surround the Yongwa Quarry are farmers. The major food crops produced in these villages are maize, cassava and plantain. Animal husbandry is also practiced in this village, with piggery, sheep, goats and poultry farms as some of the main engagements. A major environmental problem arising from these farming activities is organic waste disposal. In our survey of the community, we realized that animal wastes from farms were disposed of close to animal pens. Since the pens were located close to human habitation, it created significant environmental health issues for those households. Cassava wastes from cassava processing plants were also disposed of close to these plants.

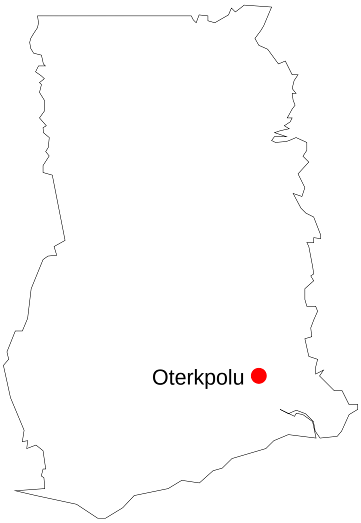

Figure 1. Location of the Yongwa quarry site in Ghana

2.2. Compost Production

Pig manure and cassava wastes were obtained from villages near the Quarry and composted at the plant nursery of the Quarry, applying an open-windrow composting technique [3]. The composting process involved heaping a mixture of pig manure and cassava wastes in a ratio of 2:1. That is, each composting windrow consisted of about 100 kg of pig manure and 50 kg of cassava waste. These were mixed and heaped into a cone (Figure 2). The composting windrow was watered occasionally to maintain appropriate moisture for microbial action. It was also turned twice a week to facilitate temperature distribution and uniform decomposition of organic material. It took one and half months for the compost to mature.

2.3. Soil Sampling

The site where the experiment was conducted was bare and somewhat rocky. With the aid of a shovel, initial soil samples (up to a depth of 5 cm) were collected from the site into polythene bags for soil analysis. The site was then divided into three plots, each with an approximate dimension of about 20 x 8 m. Thus, the initial soil samples were collected prior to dividing the site into plots. Final soil samples were collected from each plot approximately three months after treatment. All the soil samples were sent to the laboratory for analysis.

2.4. Field Treatment and Re-vegetation

There were two experimental plots (Plots 1 and 2) and one control plot (Plot 3) (Figure 3). The compost produced was applied to plant *M. pruriens* seeds on one experimental plot. On the other experimental plot, the *Mucuna* was planted without the application of compost. The control plot was left blank, without any intervention.

As a creeping plant, the *Mucuna* provided potential for protection against erosion. It has the added advantage of being a leguminous plant capable of fixing atmospheric nitrogen into soil nitrogen [5,6,7]. Therefore the choice of *Mucuna* species for re-vegetation in combination with compost application, was anticipated would help improve the fertility of the soil and facilitate plant growth. This is critical for future food production on such re-vegetated lands, once decommissioning has taken place. The compost application was done at pointsof planting. The advantage of this approach is that it allows judicious use of the compost when reclaiming very large tract of land such as a quarry site. Three seeds of *M. pruriens* were planted at each point and planting was spaced at an interval of about half a meter. There were approximately 80 planting points per plot. The planting was done on 13th June, 2014. The *Mucuna* seeds were obtained from the Crop Research Institute of the Centre for Scientific and Industrial Research located at Fumesua, Kumasi, Ghana.

Figure 2. Composting windrows

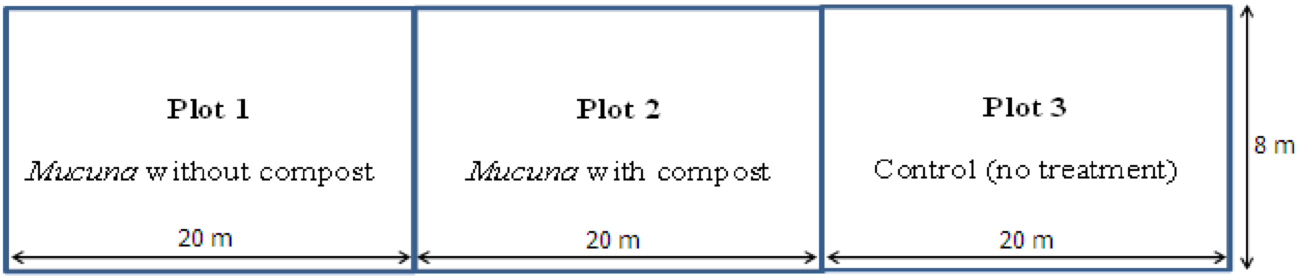

Figure 3. Experimental design

2.5. Growth Rate of *Mucuna* and Biodiversity Assessment

The growth rate of the *Mucuna* species was evaluated using changes in leaf size with time. Twenty *M. pruriens* leaves were sampled from each of the experimental plots once a month on 13th July, 13th August and 13th September, 2014 to evaluate the growth rate of the plant. The species richness of plants that colonised the experimental sites within the three months of planting the *Mucuna* species was noted and identified by plant taxonomists.

2.6. Soil Analysis

Soil samples were analysed in the laboratory for various soil fertility parameters including (nitrogen (N), phosphorous (P), potassium (K) and carbon (C)). The initial samples as well as samples from each plot were analysed in triplicates. One hundred grams (100g) of each soil sample was weighed and oven dried at a temperature of 105 °C for 3 hours. This enabled maximum removal of moisture from the samples. Each sample was subsequently allowed to cool at room temperature (about 25 °C). The samples were then ground with a porcelain mortar and pestle and sieved through pores of diameter 0.1 mm. Total N was analysed using an Automated Kjeldahl Distillation System (model KA-ZDDW-II). Total P was determined by first acid digesting the samples [8] followed by colorimetric measurement applying spectrophotometer. Total K was determined after acid digestion with Ternary mixture (20 ml $HClO_4$:500 ml HNO_3:50 ml H_2SO_4) using flame photometer. Organic carbon was determined by the wet oxidation method [9].

3. Results and Discussion

3.1. Growth Rate of *Mucuna* and Colonisation of Plots

The *Mucuna* species grew at a faster rate on the plot where the compost was applied, using change in leaf size as a measure of growth rate (Figure 4). The growth rate of the *Mucuna* on the plot with compost was about twice its growth rate on the plot without compost. There was a gradual increase in plant species richness according to the order: control plot < plot of *Mucuna* without compost < plot of *Mucuna* with compost (Figure 5). That is, the rate of colonisation of the plots was least on the control plot and highest on the plot planted with *Mucuna* applying compost amendment. While only one species of plant was observed on the control plot, five (5) different plant species colonised the plot where the *Mucuna* was planted without using compost. There were eleven (11) different species that colonised the plot where the *Mucuna* was planted with compost amendment (Table 1). The control plot was colonised by only *Axonopus sp.*, a grass that also thrived on the experimental plots. It is worth noting that several of the colonisers have economic benefits. For instance, *Talinumtriangulare* is a commonly eaten vegetable in Ghana. Aqueous and ethanol extracts of *Tridaxprocumbens* have been shown to possess anti-malaria properties[10], while *Euphorbia hirta* is reportedly potent against various types of pathogenic bacteria and plasmodium, which causes malaria [11,12].

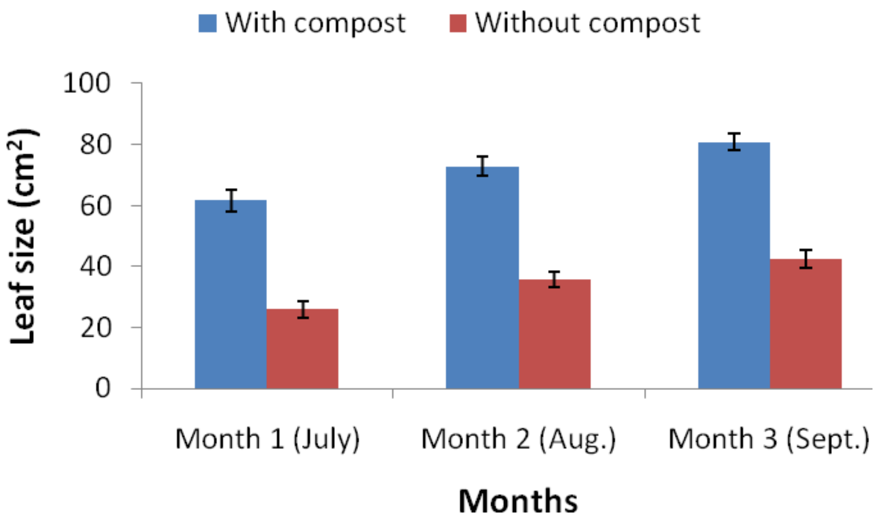

Figure 4. Changes in leaf size of *Mucuna* species on plots with and without compost over a period of three months.

Table 1. Plant species that colonised experimental and control plots

Control Plot	*Mucuna* without Compost	*Mucuna* with Compost
Axonopus sp.	*Centrosemasp.*	*Phyllanthusurinaria*
	Tridaxprotcumbens	*Portulacaoleracae*
	Euphorbia hirfa	*Cardiospermumgrandiflorum*
	Axonopus sp.	*Cleomesp.*
	Lantana sp.	*Solanumturrum*
		Chromolaenaodorate
		Centrosemapuberscens
		Tridaxprocumbens
		Physalismicrantha
		Axonopus sp.
		Talinumtriangulare

3.2. Effects of Treatments on Soil Fertility

Presumably, the plot treatment affected soil characteristics, which in turn influenced the diversity of plant species that colonised the plots. Soil analysis was done to ascertain this hypothesis. The soil was generally alkaline, irrespective of treatment, with pH range approximately 8.3 – 8.6. (Table 2). But *Mucuna* species has also been reported as tolerant to acidic soils [13]. The *Mucuna*, thus, could be useful in treating soils in a broad pH range. The nutrient content (N, P, K, C) of the soil was expectedly low, considering that the top soil was removed and it was left with a somewhat rocky surface. The treatment with compost however showed a relatively increased content in soil nitrogen, phosphorus and organic carbon. Electrical conductivity was also relatively high in the compost treated soil and may portend increased mineral content. The concentrations of potassium and organic carbon in the initial soil (i.e. before treatment) were not different from the contents of the respective nutrients in the soil from the plot of *Mucuna* without compost. This suggests that treatment of the soil by planting *Mucuna* without any further treatment did not vary potassium and organic carbon in the soil. However, when compost was applied to cultivate the *Mucuna*, the concentration of potassium and organic carbon increased significantly, $p<0.001$ in each case.

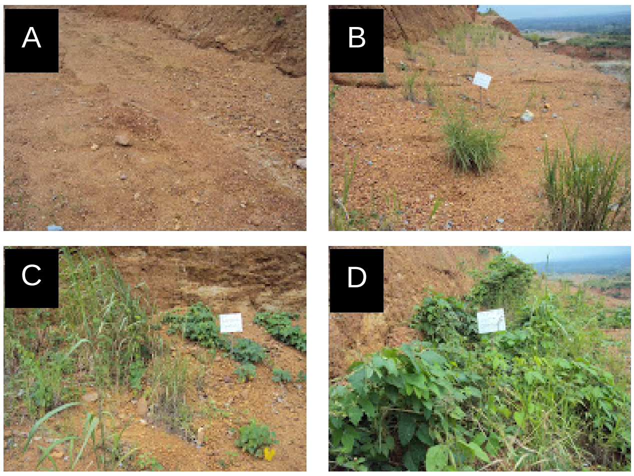

Figure 5. Image of site before experiment and plant species diversity attracted to experimental and control plots over a period of three months (A = before experiment; B = control plot; C = plot of Mucuna without compost; D = Plot of *Mucuna* with compost)

Comparing the level of nitrogen in the soil before the experiment (initial soil samples) to the levels in soil from the control plot after three months, it appeared that the control plot got naturally enriched with nitrogen from sources that cannot be immediately explained (Table 2). Planting of the *Mucuna* without application of compost marginally increased the nitrogen content above the levels in the control soil. The soil appeared further enriched with nitrogen when the *Mucuna* was planted with compost. The variations in soil nitrogen among plots was statistically significant ($p=0.002$). It is assumed that there was a double dose of nitrogen enrichment on the plot where

Mucuna was cultivated in the presence of compost. The compost has the ability to enrich the soil with nitrogen [14], while the *Mucuna*, as a leguminous plant, was expected to also fix atmospheric nitrogen into the soil [7]. Thus, although the *Mucuna* has the ability to fix nitrogen into soil, cultivating it with compost amendment provided further enrichment of soil nitrogen, as well as relative increase in soil phosphorus and organic carbon (Table 2). This relative increase in soil fertility perhaps influenced the growth rate of the *Mucuna* with compost amendment (Figure 4).

Table 2. Soil characteristics at experimental site before and after treatment

	pH	EC (µS/cm)	Total N (%)	Total K (%)	Total P (%)	Organic C (%)
Initial soil	8.64	143.50	0.34	0.01	0.01	0.28
After treatment						
Control	8.30	100.00	0.77	0.01	0.01	0.20
Without compost	8.26	127.67	0.86	0.01	0.01	0.22
With compost	8.31	157.67	1.02	0.01	0.11	0.73

3.3. Hypotheses Explaining Plant Species Richness on Plots

An intriguing aspect of the results is the increased richness of plant species that colonised the plot with compost/*Mucuna* treatment. Was it by chance or were there key factors that perhaps favoured early colonisers to flourish on this plot? If we assume the latter, then there could be two plausible explanations per the present study design, with the *Mucuna* behaving as a quasi-nurse plant. This is because its development seemed to facilitate the growth and development of other plants that invaded the plots [15,16]. First, the relative increase in soil fertility regarding the coupled intervention of compost/*Mucuna* treatment possibly provided favourable grounds for dispersed seeds of colonisers to flourish. The second plausible explanation is that seeds of certain invasive species in forest regions might require a bit of shade to germinate. Considering the increased growth rate of the *Mucuna* with compost amendment, the broader *Mucuna* leaves derived from this treatment perhaps provided limited but useful shade for the protection and germination of certain dispersed seeds. These hypotheses appeared more apparent given that the colonisers thrived in close proximity to well-growing *Mucuna* plants (Figure 5). It may be a symbiotic association in which the colonisers benefited from nitrogen fixed by the *Mucuna* and probably the shade provided by the *Mucuna* leaves as discussed earlier. In return, colonizers grew relative fast and provided support for the *Mucuna* (a climbing legume) to climb.

The present study has provided clear evidence that *M. pruriens*, especially when grown with compost amendment on degraded land, is an innovative way to kick start a re-vegetation process. The *Mucuna* has shown good potential to do well in a stressed environment when the soil was amended with compost. The compost/*Mucuna* combination provided relative improvement in soil fertility characteristics. For instance, soil N, P and C showed relatively elevated content creating quite fertile grounds for other plants species dispersed to this plot to flourish. Given the general supporting role of the *Mucuna* to the growth of the other species that invaded the plot, it was concluded that the *Mununa* is potentially a quasi-nurse plant that can establish symbiotic relationship with new plant colonies to initiate ecological restoration of a degraded quarry site. The potential of the compost/*Mucuna* intervention of revitalizing degraded land could be extended to the adjoining farming communities to improve soil fertility for crop cultivation. This would limit the dependence on costly chemical fertilizers, while encouraging the production of organic crops.

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