Composting for quarry site rehabilitation

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Abstract

This study evaluated the potential and coupling effect of compost and *Mucuna* (*Mucuna* spp. var. Ghana) 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 colonizing plant species. When the *Mucuna* was planted with compost amendment, eleven different plant species emerged on the plot, which also showed relatively elevated contents of nitrogen, phosphorous and organic carbon. The increments in the respective soil nutrients were marginal but 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 colonizers provided support for the *Mucuna* to climb, in return for the benefits these new colonies received from the *Mucuna*. The concepts described in this study are of relevance to both the company and society. They could be applied to initiate re-vegetation of the Yongwa Quarry site during future decommissioning work to restore the site. The potential of the compost/*Mucuna* intervention in revitalizing degraded land could 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.

1. Introduction

Traditionally, the science of composting has been used for sanitary purposes of managing biodegradable wastes and to provide organic fertilizer. As we explore composting technology to manage biodegradable waste in Ghana, a major challenge has been the need to attract significant market for compost products. It is believed that innovative applications of compost would increase its scope of utilization and attract a wider market (Hogarh, 2003).

In the present study, we explored the option of applying compost to reclaim contaminated land at the Yongwa quarry site in Ghana. During quarry activities, 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 (Wong, 2003). 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 (Nason et al., 2007). 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 (Hogarh et al., 2008). There is also evidence to suggest that applying compost may immobilize contaminants in soil and limit their bioavailability (USEPA, 2007).

In carrying out this work, we present a model that would ensure a win-win situation for the company and the community. We have identified that the villages surrounding the Yongwa Quarry, as typical farming communities, generate a lot of putrescible organic wastes. Some of these wastes include the peels of plantain, cassava and various fruits, corncob, wastes from domestic livestock such as fowl, goat, sheep, etc. These wastes when left unattended attract rodents that are destructive to both farm produce and domestic properties.

2. Aim and Objectives

The aim of this study was to apply organic wastes generated in the villages near the Yongwa Limestone Quarry to produce compost for soil amendment and re-vegetation of plant species at the degraded quarry site. The specific objectives of the study were to:

i. produce compost using organic wastes from the nearby villages;
ii. apply the compost to improve soil properties;
iii. demonstrate, through field application, the effectiveness of compost-amended soil to support re-vegetation at the Yongwa Quarry site.

3. Methodology

3.1. Study area

The study was conducted at the Yongwa Limestone Quarry site in Ghana. The Yongwa Quarry is located near Otorkporlu in the Eastern Region of Ghana. 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 Otorpkorlu and 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.

3.2 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 (Hogarh et al., 2008). 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 1). 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.

Figure 1: Composting windrows

3.3. Soil sampling

The site where the experiment was conducted was bare and somewhat rocky (Figure 4). With the aid of a shovel, initial soil samples (up to a depth of 5 cm) were collected from the site into polythene bags. The site was then divided into three plots, each with an approximate dimension of about 8 x 20 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.

3.4. Field treatment and re-vegetation

There were two experimental plots (Plots 1 and 2) and one control plot (Plot 3) (Figure 2). The compost that was produced was applied to plant *Mucuna* seeds on one experimental plot. On the other experimental plot, *Mucuna* was planted without the application of compost. Three *Mucuna* seeds were planted at each point and planting was spaced at an interval of about half a meter. The *Mucuna* species were planted on 13th June, 2014. Our initial intention was to apply *Luffa* species to initiate re-vegetation at the site. However, it was difficult getting viable *Luffa* seeds in the rainy season. One of the major advantages of the *Luffa* species is that it is a creeping plant that spreads to cover the ground and effective at checking against erosion. In its absence, the *Mucuna* species, a creeping leguminous plant was applied. The *Mucuna* seeds were obtained from the Crop Research Institute of the Centre for Scientific and Industrial Research located at Fumesua, Kumasi, Ghana. As a creeping plant, it provided potential for protection against erosion. It has the added advantage of being a leguminous plant capable of fixing atmospheric nitrogen into soil nitrogen (Sanginga et al., 1996). 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 points of 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 mined site. The control plot was left blank, without any application.

Plot 1	**Plot 2**	**Plot 3**
Mucuna without compost	*Mucuna* with compost	Control (no treatment)

Figure 2: Experimental design

3.5 Growth rate of Mucuna and biodiversity assessment

The growth rate of the *Mucuna* species was evaluated using changes in leave size with time. Twenty *Mucuna* leaves were sampled from each of the experimental plots once a month on 13^{th} July, 13^{th} August and 13^{th} September, 2014 to evaluate the growth rate of the plant. The diversity of plants that colonized the experimental sites within the three months of planting the *Mucuna* species was noted and identified. The initial proposal of this research included an assessment of below ground biodiversity. This however could not be conducted for logistic and budgetary constraints, given the inability to secure a high powered electron microscope required for this evaluation.

3.6. Soil analysis

Soil samples were analyzed 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 analyzed in triplicates. 100 g 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 analyzed using an Automated Kjeldahl Distillation System (model KA-ZDDW-II). Total P was determined by first acid digesting the samples (Okalebo et al., 2002) 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 (Walkley and Black, 1934).

3.7. Stakeholder meeting

Farmers in the community were engaged in a focus group discussion, in which the concept of compost production (from the organic wastes they generate) was introduced to them. The prospects of organic farming and the health benefits associated with consuming organic products were discussed.

4. Results and Discussion

4.1. Growth rate of Mucuna and colonization 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 3). 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 diversity according to the order: control plot < plot of *Mucuna* without compost < plot of *Mucuna* with compost (Figure 4). That is, the rate of colonization 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 colonized the plot where *Mucuna* was planted without using compost. There were thirteen (13) different species that colonized the plot where *Mucuna* was planted using compost (Table 1). A sample each of all the plant species identified on the plots was collected and each pressed in-between two sheets of clean newsprint papers. The samples were sent to a plant taxonomist at the Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology, who helped in the identification of all the plant species. The control plot was colonized by only *Axonopus sp.*, a grass that also emerged on the experimental plots. The different species on the experimental plots were also identified and listed in Table 1. It is worth noting that several of the identified species have economic benefits. For instance, *Talinum triangulare* is a commonly eaten vegetable in Ghana. Aqueous and ethanol extracts of *Tridax procumbens* have been shown to possess anti-malaria properties (Appiah-Oppong et al., 2011), while *Euphorbia hirta* is reportedly potent against various types of pathogenic bacteria and plasmodium, which causes malaria (Tona et al., 2004; Sudhakar et al., 2006).

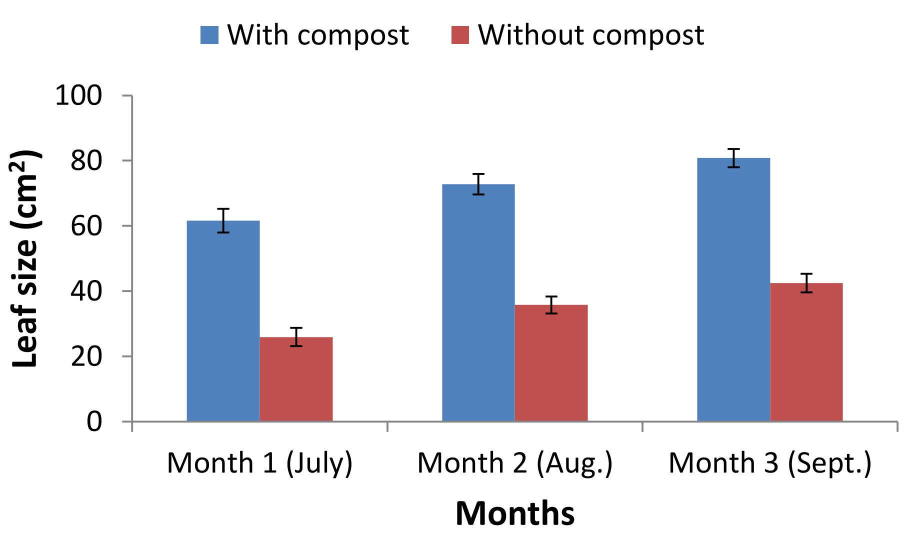

Figure 3: Changes in leaf size of *Mucuna* species on plots with and without compost over a period of three months.

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 colonized the plots. Soil analysis was done to ascertain this hypothesis. The soil was generally alkaline, irrespective of treatment (Table 2). 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.

Before experiment | Control plot | Plot of *Mucuna* without compost | Plot of *Mucuna* with compost

Figure 4: Image of site before experiment and plant species diversity attracted to experimental and control plots over a period of three months.

Table 1: Plant species that colonized experimental and control plots

Control Plot	*Mucuna* without Compost	*Mucuna* with Compost
Axonopus sp.	*Centrosema sp.*	*Phyllanthus urinaria*
	Tridax protcumbens	*Portulaca oleracae*
	Euphorbia hirfa	*Cardiospermum grandiflorum*
	Axonopus sp.	*Cleome sp.*
	Lantana sp.	*Solanum turrum*
		Chromolaena odorate
		Centrosema puberscens
		Tridax procumbens
		Physalis micrantha
		Axonopus sp.
		Talinum triangulare

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 variation in soil nitrogen between the control and experimental plots was statistically significant ($p=0.3$). It is assumed that there was a double dose of nitrogen enrichment on the plot where *Mucuna* was cultivated applying compost. The compost has the ability to enrich the soil with nitrogen (Adamtey et al., 2010), while the *Mucuna*, as a leguminous plant, is expected to also fix atmospheric nitrogen into the soil (Sanginga et al., 1996). 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 3).

Figure 5: Some of the dominant plant species that colonized the experiment plots

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 diversity on plots

An intriguing aspect of the results is the increased diversity of plant species that colonized the plot with compost/*Mucuna* treatment. Was it by chance or were there key factors that perhaps favoured early colonizers 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 (Castro et al., 2002, Ren et al., 2008). First, the marginal increase in soil fertility regarding the coupled intervention of compost/*Mucuna* treatment possibly provided favourable grounds for dispersed seeds of colonizers 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 *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 appear more apparent given that the colonizers thrived in close proximity to well-growing *Mucuna* plants (Figure 4). It may be a symbiotic association in which the colonizers 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.

3.4. Community education

Figure 6: Community education on composting through a focus group discussion.

Residents in villages from where the pig manure and cassava wastes were collected for this project were curious about what we did with the waste. Hence, a focus group discussion was arranged with the opinion leaders and farmers from these villages at the tail end of this project, to share the information regarding the potential of the compost/Mucuna treatment for soil fertility improvement (Figure 6). The meeting took place at the Boaninya Community school premises in one of the villages near the Quarry on 5th September, 2014, with about 30 farmers in attendance. It emerged that most of the farmers were familiar with and practiced application of chemical fertilizers, nevertheless composting was not an entirely new concept to them. They appeared aware of the importance of compost as against chemical fertilizer, but lacked the technical know-how and initiative to prepare the compost. Again, they were familiar with the dangers associated with the use of some agro-chemicals but said they had no option than to use such chemicals to improve crop yield. The meeting provided them with useful practical insights regarding the processes involved in composting and the advantage that could be further achieved if the compost is applied in combination with a leguminous cover crop. Apparently most of the farmers saw the compost windrows we prepared in this project, which was enough proof that composting technology can be very simple. The fact that composting was cost effective, nutrient rich and also provided an environmentally friendly means of managing biodegradable waste stimulated the interest of many of the farmers, especially as subsidies on fertilizers are gradually being removed and the cost of chemical fertilizers on the local market has increased.

3.5. Added value of project for biodiversity, society and the company

The present study has provided clear evidence that *Mucuna* spp., especially when grown with compost amendment on degraded land, is an innovative way to kick start a re-vegetation process. The *Mucuna* 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 of the Yongwa Quarry site during future decommissioning work to restore the site. For communities, especially in the immediate villages surrounding the Yongwa Quarry, this project has provided first hand evidence of utilizing wastes that the community generated to produce organic fertilizer for soil amendment. The potential of the compost/Mucuna intervention of revitalizing degraded land could be extended to local 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.

4. Conclusion

Although aspects of the original protocol expressed in the proposal were slightly modified for logistics and financial constraints, this did not affect the underlying theme of this research. We demonstrated the application of simple composting technique to manage organic wastes generated in villages nearby the Yongwa Quarry. Compost was successfully produced from pig manure and cassava residues, which constituted major organic waste issues in the surrounding villages. The compost was applied to plant a local leguminous species, *Mucuna* spp., on degraded site at the Quarry. 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.

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