CHALLENGES AND ACTIONS REGARDING THE REHABILITATION OF DEGRADED LANDS: CASE STUDY FROM THE PACIFIC ISLAND OF GUAM

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ABSTRACT

Severely eroded lands of southern Guam are referred to as BadLands. These are actively eroding areas of very deep, well–drained saprolite derived from tuff and tuff breccia. These badlands are exposed to overland flow, wind and rain causing sever erosion as the result of rapid runoff from the pitted, sloping sites void of vegetation. Through soil removal or sediment transport, erosion also alters the inherent physical and chemical properties of these soils. This alteration resulted in degradation, in turn affecting the environment as well as water quality in the down stream. The on-site damage from erosion is indeed a problem to environmental ecosystem of the island. Sediment lost due to erosion clogs rivers, lakes, and waterways. It reduces the water storage capacity of reservoirs and canals and increases flooding.

The challenge facing soil and environmental scientists is to develop conservation and restoration strategies at the farm as well as at the watershed level that address crop production and natural resources protection needs, within a framework of increasing environmental and financial constraints. In our soil conservation program at the College of Natural and Applied Sciences of the University of Guam we have adopted integrated approaches to evaluate a variety of strategies, including the effect of conservation tillage and residue management, crop rotation with leguminous plants (sunnhemp) as green manure as well as the use of composted organic wastes as soil amendment for organic matter build up, all for soil rehabilitation and restoration of the badlands in southern Guam. In a companion study we are evaluating the effectiveness of Vetiver technology as a sediment trap to mitigate sediment transport in a typical watershed basin in southern Guam. This paper discusses the methodology as well as up to date data that shows the effect of Vetiver technology on sediment trapping at the watershed level.

INTRODUCTION

Soil erosion is the number one problem causing land degradation and low agricultural productivity in southern Guam. In addition to land degradation and productivity, coral reef degradation due to soil erosion and sedimentation is of major concern to the people of Guam.

Water erosion is the most severe form of erosion from a pollution standpoint, because soil that becomes detached by water is eventually concentrated in waterways, posing threat to human and marine environment. This type of erosion constitutes the most serious form of erosion on Guam's soils (GEPA, 1986) especially on the bad lands of southern part of the Island. As referred to by Lewis (1999), transport of sediment out of a badland basin, into a new sedimentary system, promotes a spectrum of environmental and ecological changes ranging from wetlands formation and river turbidity to coastal modification and habitat destruction. These natural resources are an integral part of *quality of life* and viability of *the tourism industry*. Both are severely altered by unchecked badlands formation (Lewis, 1999).

Soils are the long-term capital on which a nation builds and grows (Wilding, 1994). It is a basic component of ecosystems and is one of the most vulnerable to degradation through mismanagement (Wilding, 1994).

Soil erosion and soil organic matter depletion are primary processes of land degradation that generate many critical changes in soil characteristics that affect the essential soil biological, chemical, and physical processes influencing soil productivity. Soil degradation adversely impacts the natural ecosystem and sustainability of the productive lands by decreasing soil quality. The land area lost to soil erosion and degradation has to be replaced by bringing new land under production which involves encroachment of: (i) ecologically-sensitive eco-regions; (ii) marginal or steep lands, and (iii) regions with aesthetic, cultural and historical values and perspectives (Lal, et.al., 1997). Soil degradation on agricultural lands is a symptom of miss-use and miss-management that jeopardizes the integrity of soil's self-regulatory capacity.

Erosion encompasses detachment, transport, and deposition of soil particles by erosive forces of wind, gravity, and raindrops and surface flow of water (Nearing, et.al., 1994). The effectiveness of rainfall and run-off in detaching and transporting soil particles downstream is increased by several times if the soil is loose and unprotected by any vegetation cover (Lal, 1987). The cover not only reduces raindrop impact, it also increases the resistance to the flow of run-off water.

Erosion is a process where wind and water facilitate the movement of topsoil from one place to another. Through soil removal and nutrient transport via sediment, the soil erosion alters the inherent physical and chemical properties of soils. This alteration may result in degradation, in turn affecting the environment as well as the processes that regulate the productivity and sustainability of an ecosystem. Water erosion is more detrimental to soils globally both by the volume of soil removed and area of land influenced.

Deterioration in soil physical properties causes accelerated soil erosion, and the latter aggravates the degradation of soil physical, chemical and biological properties. The price of soil erosion and land degradation includes a heavy toll on the environment. Soil degradation also has adverse impact on eutrophication of surface waters, contamination of groundwater, and increase in the atmospheric concentration of greenhouse gases, e.g., CO_2, CH_4, NO_x (Lal, et al., 1997). Adverse changes of soil physical, chemical, and biological properties affected by erosion and degradation can be reversed through proper rehabilitation measures and erosion control practices.

Two of the most important agricultural resources, land and water are crucial for the well being of the Asia- Pacific region, which is home to nearly three-fourths of the world's agricultural population. A major problem in this region is land degradation, which is largely caused by depletion of soil nutrients due to intensive agriculture and also by water and wind erosion. A growing population is adding to pressure on arable land. To meet its increasing food needs, the region will have to produce more food largely from the existing farmlands because there is very little land available for physical expansion. This can be done only by increasing crop yields by improving soil quality and maintaining the environmental integrity.

Many farmers prepare land by tilling or plowing their fields to produce a smooth planting surface devoid of vegetation. This process, however, creates a soil surface that is very vulnerable to erosion. Some farmers in western societies have been using a technique known as zero or no-tillage systems to reduce the erosion problem. Countries in the Asia and Pacific region however need to integrate appropriate conservation techniques within their limited resources in order to control erosion and mitigate severe land degradation. Appropriate technologies should also be adopted in hilly areas to reduce sedimentation and prevent soil erosion, which is a serious problem in lands with steep slope. These include correct tillage practices, and slope stabilization techniques such as Vetiver system.

Promoting sustainable forms of natural resource management is a challenge land users are unable to tackle solely on their own initiative. Soil and land degradation remains an unresolved problem of global environmental change. There is a need for concerted international action that directly addresses this issue at the global level.

Some of the steps toward achieving a sustainable agriculture and natural resources preservation include: a) reduction of soil erosion, b) enhance soil productivity through soil organic matter maintenance and/or accretion, c) improve crop management through diversification and rotation of crops, and d) protect the environment from non-point source pollution due to surface runoff and chemical and sediment transport.

Although, many soil conservation technologies can be combined to reduce erosion rates, reduced tillage can play a key role in this effort by reducing soil erosion, decreasing weed pressure through maintenance of surface mulch, and enhancing soil productivity through crop residue and organic matter maintenance. The principal method of controlling soil erosion and its accompanying rapid water runoff is to maintain adequate vegetative cover. Plant cover intercepts and dissipates the energy in raindrops before they strike the soil, enabling the water to reach the soils without damage. Furthermore, plant stems, roots, and organic matter help control runoff and encourage water percolation into the soil.

Some of the Agricultural Practices that lead to Accelerated Soil Erosion:

- Overgrazing of animals – overgrazing leave the soil surface bare and subject to rain drop impact, hence to soil erosion.

- Planting of a monoculture - can lead to erosion for several reasons. A monoculture is harvested all at one time, which leaves the entire field bare and the natural rainfall is not retained by the soil and flows rapidly over the surface rather than into the ground.

- Tilling or plowing - it involves loosening the soil particles, incorporating oxygen and getting rid of weeds, however, it also increases the likelihood of erosion because it disturbs the natural surface and protective vegetation.

- Crop removal. The continuous and complete removal of crops without leaving the plant residue on the soil surface not only increases the soil susceptibility to erosion due to exposure but it also causes soil organic matter depletion. Organic matter has the ability to absorb a lot of rainwater and without it erosion is increased to an alarming level.

Many of these practices have resulted in land degradation land across the globe.

Challenges and Actions:

Problems of soil erosion can be stopped and/or reduced if appropriate techniques are employed for each specific condition. The conservation techniques that are commonly used to reduce or eliminate erosion are: contour farming; terracing; no-till or zero tillage cultivation; strip farming; and above all application of organic matter for improving the quality of soil for minimizing the effects of erosive forces while maintaining the fertility of the soil for agricultural sustainability.

Soil is a living thing, drawing the energy for its continued existence from the organic matter added by the green plants, the synthesizer species that inhabit its surface. The other components of the biota that inhabit the land surface, the decomposer species, also rely on the organic matter produced by the green plants for their sustenance. In tropical environment where high temperature and much rainfall are the dominant factor, a heavy demand from the decomposer species reduces the quantity of organic matter that goes to the soil. If this residual quantity, either as litter on the surface or incorporated into the soil, is not sufficient to maintain the population of micro-organisms the soil system goes into decline and the component parts begin to fall to pieces. As the system loses its coherence, the particles of the surface become liable to movement by wind or water, and the soil become liable to sever erosion.

In our soil conservation program at the College of Natural and Applied Sciences of the University of Guam we have adopted integrated approaches to evaluate a variety of options, including the effect of conservation tillage and residue management, crop rotation with leguminous plants (sunnhemp) as green manure as well as the use of composted organic wastes as soil amendment for organic matter build up, all for soil rehabilitation and restoration of the badlands in southern Guam. In a companion study the effect of Vetiver technology as sediment trap to mitigate sediment transport from a typical watershed basin in southern Guam is also being evaluated as erosion control strategy for the hilly areas.

The projects described herein provide sufficient descriptive information with respect to soil properties and important quality indices affecting crop productivity and agricultural sustainability. Of particular interest is the influence of organic matter application to enhance the overall soil quality particularly the aggregate stability for minimizing the effect of erosion forces by water. This paper also evaluates the effectiveness of Vetiver technology to control sediment loss at the watershed level.

Statement of Problem, Rational, and Significant:

The intensity of badland erosion and its effects on the environment is at its threatening stage. Severe erosion and transport of sediments out of badlands into the streams, promotes a spectrum of environmental and ecological changes ranging from wetlands formation and river turbidity to coastal modification and habitat destruction in southern Guam (Lewis, 1999). These natural resources are an integral part of quality of life and viability of the tourism industry for Guam's economy. Both are severely altered by unchecked badlands formation (Lewis, 1999).

Sedimentation as the result of runoff is the principle anthropogenic threat to Pacific Island of Guam. Runoff water is characterized by flash floods of high velocity but short duration. The rapid flow is attributed to low soil infiltration, high proportion of rain converted to overland flow, and scanty or no vegetation cover due to wildfires. In the areas that protective vegetation cover is at its minimum, and the soil quality is poor (weak aggregate stability due to low organic matter content), the soil is therefore subjected to the high shearing force of overland flow.

The on-site damage from erosion is indeed a problem to the island's ecosystems especially in the southern regions. Eroded sediment clogs rivers, lakes, and waterways. It reduces the water storage capacity of reservoirs and canals and increases flooding. Sedimentation is damaging to streams, rivers and eventually to the near-shore coral reef ecosystem.

Awareness of badland erosion and its effects on the environment are increasing. Erosion control practices should therefore be designed to conserve soil and natural resources and maintain the integrity of ecosystems while protecting the environment of the island

The challenge facing soil and natural resource scientists is to develop strategies in order to improve the soil quality not only for controlling erosion but also introduce new maintenance techniques for crop production within a framework of increasing environmental and financial constraints.

The two case studies presented here will emphasize on the agronomic value of compost on soil quality enhancement for crop productivity and improved aggregate stability for increasing resistance to soil erosion forces as well as the effectiveness of Vetiver technology for sediment trapping as a watershed management strategy.

CASE STUDIES

<u>Case study No. 1</u>

Using composted organic wastes as soil amendment for crop productivity and agricultural sustainability in the island of Guam.

OBJECTIVE (S)

In our soil program at the University of Guam, we are evaluating the use of composted organic material as an alternative to synthetic fertilizers to increase yield and enhance crop productivity. Our main objective is to develop management strategies and use available resources to improve soil quality for maintaining agricultural sustainability while conserving natural resources and preserving environmental quality.

MATERIAL AND METHODS

The composting procedure is being conducted at the Inarajan Agricultural Experiment Station in southern Guam. In this study, tree trimmings from the roadsides, chicken, hog and horse manure from local farmers and ranchers and wood chips from typhoon debris were used for compost production.

There are many methods of composting organic materials. These include active windrow (with turning), passively aerated windrow (supplying air through perforated pipes embedded in the windrow), active aerated windrow (forced air), bins, silos, and anaerobic digestion (Humenik, and J.R. Miner, 1983). In this project however, we employed passively treated compost piles and supplied air through perforated pipes embedded in the pile, with occasional mixing of the compost by backhoe. Samples were collected from different sections of the compost pile for nutrient characterization before the compost was applied on the treatment plots. Seven samples were collected randomly and were mixed to produce one composite sample and brought to the lab for analysis. Total nitrogen with Kjeldahl (Bremner and Mulvaney, 1982) and NO_3 by QuikChem -LACHAT was determined. Soluble phosphorus was determined colorimetrically by using sodium bicarbonate (Olsen and Sommers, 1982). The pH was determined in a 1:5 soil:water paste using a combination electrode.

In the second stage of the experiment we applied the composted organic material on research plots as a fertilizer in order to evaluate the agronomic value of the organic compost on crop production from the soil under study. Also the effect of compost as soil amendment for enhancing soil quality was evaluated.

Twelve field plots (25 X 18ft^2) were set up at the Inarajan Agricultural Experiment Station in southern Guam for this project. The soil under study for this investigation is Akina series (Very fine, kaolinitic, isohyperethermic Oxic Haplustalf) formed in volcanic residuum (USDA-SCS, 1988). Composted organic wastes were applied at 0 (control), 5, 10, and 20 tons per hectare and replicated three times. Drip irrigation system was employed during the dry season.

RESULTS

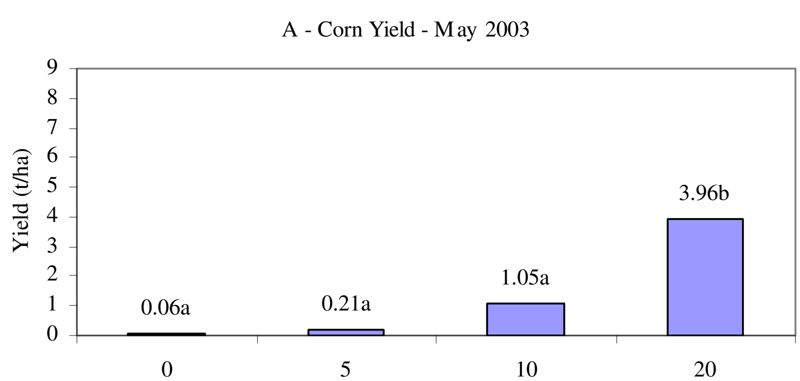
The characteristics and range of compositional values of the compost before the land application of the organic material are presented in Table 1. As shown in table 1, the carbon to nitrogen ratio of the compost before the land application is relatively high. Therefore, the compost was incorporated four inches into the soil one week before the corn seeds were planted in order to allow the carbon to nitrogen ratio stabilize itself during this period. Vigorous growth during the growing season reflected sufficient nitrogen release by the compost indicating that the initial high carbon to nitrogen ratio did not suppress plant growth.

The results indicated that under the unique climatic conditions of Guam, land application of organic compost enhanced soil quality and increased soil fertility considerably. As shown in Table 2, 3, and 4 considerable improvements in bulk density, soil organic matter content, soil pH, nutrient distribution, and other soil quality parameters occurred with increased application rate of the composted organic material on the soil under treatment. Also, in order to evaluate the effect of composted organic waste on soil quality for erosion control, a set of rainfall simulators are being built to measure the infiltration rate and runoff as they are affected by different compost application rates (data not available at this time). Sediment loss from each treatment plot will be measured to evaluate the effectiveness of composted organic waste on erosion control.

Data obtained from the first trial indicated that as the compost application rates were increased from 0 tons per hectare (control) to 5, 10 and 20 tons per hectare, the soil CEC (cation exchange capacity), one of the major soil quality indexes, was also increased, indicating a considerable improvement in nutrient exchange capacity of the soils treated with organic matter amendments (Table 2, 3, 4). A significant yield increase (Fig. 1A, 1B, 1C) in plots with compost application rate of 10 and 20 tons per acre provides evidence of these improvements.

Following the first harvest from dry season (May 2003) the same plots were used for re-planting during the wet season (August to December) of 2003. The same soil quality enhancement occurred following the second round of the compost application on the treated soils (Table 3). Yield results from the dry season trial showed an even higher increase in crop yield as the compost application rates were increased (Fig. 1B). A point must be made that the yield results from the second trial reflect the effect of previous compost application on these plots. In addition to yield increase, the quality of the corn crop also was improved (Figure 2). Data from the second corn harvest (December of 2003), however, showed that the yield increase from 10 tons per hectare was not much different from the 20 tons per hectare (Fig. 1B) indicating that the highest rate of compost application only promotes vegetative growth at the expense of grain production. Therefore, the third trial of the same corn planting was adjusted with the highest application rate reduced from 20 to 15 tons per hectare (Fig. 1C). The results from the third trial were then used to establish an optimum level of the compost application rate, which can then be recommended to the local farmers who are currently using organic material as the source of soil nutrient for their crops.

As was evidenced by the data thus far evaluated, land application of compost organic wastes enhanced soil quality/fertility significantly. With continued application of compost prior to each planting event, the soil quality should be further enhanced and the yields should increase as well. This is an ongoing experiment and additional data and analysis is expected to be available for later reporting.



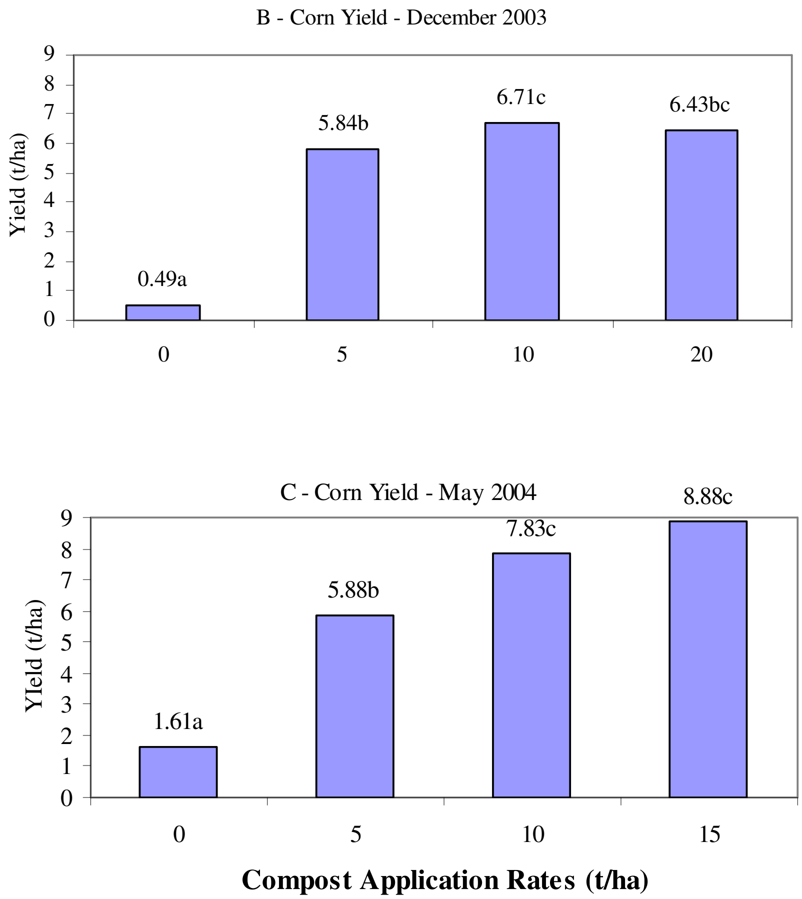


Fig.1: Yield results showing gradual increase as compost application rates were increased. [*Mean shown on the columns followed by the same letter are not significantly different according to Fisher's LSD multiple comparison test (P< 0.05)]

Fig. 2: Showing that in addition to yield increase, quality of corn crop was also improved as the result of increased compost application rate.

<u>Case Study No. 2</u>

Using Vetiver technology to mitigate sediment transport for erosion control and water quality improvement in a typical watershed in southern Guam.

THE OBJECTIVE (S)

The overall objective of this project is to assess the sediment loss from a typical southern watershed and estimate the sediment-loading rate to the near-shore coral reef originating from the upland watershed areas. Also in this project the effect of different soil surface conditions on soil erosion specially the effectiveness of Vetiver grass on trapping the sediment as erosion control strategy is being evaluated.

METHODOLOGY

This on going project commenced in May 2003 with the initial surveying and identification of possible projects sites for erosion monitoring and analysis.

Four plots (72ft X 5.5ft) are laid out on a uniformly sloped (12%) selected watershed area to estimate the sedimentation rates. Each plot is equipped with 8-inch high flume wall in order to separate the individual plot's surface treatments from each other and surroundings. Flumes are equipped with a cone shape weirs, which will direct the runoff and sediments into a collecting tank beneath the weirs. Soil texture analysis from the site revealed that the soil under study contains 54.4% clay, 20.7% silt and 24.9 % sand making it a clay soil. The organic matter content of the soils under study was determined to be 3.9% on average.

In order to evaluate the effect of different soil surface management on erosion and quantify the sedimentation and turbidity of the runoff water from each plot, the following treatments are being examined at this particular watershed:

a) Natural vegetation "As it is" treatment
b) " Vetiver technology" treatment as a restoration technique
c) "Controlled burned" treatment
d) "Exposed surface - No-cover" treatment

The above-mentioned treatments represent a wide range of conditions that are present in a typical watershed area in southern Guam. The natural vegetation condition ("as it is" treatment) is used as a control for comparison purposes. The " Vetiver technology" is used as a restoration technique in this study to evaluate the effect of Vetiver grass (Vetiveria zizanioides) on sediment trapping and the water quality conditions affected by these systems. The Vetiver grass is planted in hedgerows of 13 feet apart while sunnhemp was planted between the hedgerows as a green manure in order to provide the initial nitrogen requirement for the grass. This treatment is particularly used to quantify the sedimentation and turbidity of runoff water from the treatment plot and will develop best management practices to alleviate the impact of sedimentation and turbidity on near shore coral reefs. The purpose of the "controlled burned" condition is to evaluate the effect of new vegetation growth on soil erosion and sedimentation from soil surface under treatment. The "controlled burn" condition also represents the erosion from land denuded of vegetation by intentionally set savanna wildfires in southern Guam. In the "exposed " or no-cover treatment the plot is tilled and the soil surface is left with no cover and exposed to rain drop impact at all times to represent the degraded bare soils of southern Guam known as badlands. The purpose of this treatment is to assess the sedimentation and turbidity on near shore coral reefs attributable to runoff from these severely eroded and exposed soil surfaces in watersheds in southern Guam.

A set of suspended sediment samplers were installed in the sampling tanks for the measurement of sediment discharged from the flumes. The runoff was collected in a tank installed beneath the weir at the bottom end of each flume and the volume of runoff water is being measured at each sampling event as described. Sampling storage tank capacity (450 gallon) was based on 100 percent runoff and a 10 year, 24 hour storm events. The weirs at the end of the flumes are attached to an end trough, which is extended 8 inches into the storage tank. Storage tanks are placed beneath the collector troughs to collect the weekly runoff from each plot are measured before tanks are drained for the subsequent events. In addition to the samples from the sediment samplers, sub-samples from the runoff water are also being taken for turbidity analysis and sediment quantification.

Samples are collected twice a week during the wet season (July – December) and once a week during the dry season (December – June). Samples are brought to the lab and allowed to sit for 72 hours. When the sediments have settled, most of the water is drained and the sample is transferred into a beaker and dried at 75 degree Celsius for 48 hours then weighted to determine the sediment content collected for each treatment plots. Turbidity is measured from separate samples by using a Hatch 2100 instrument for each treatment plots.

Current Progress Updates

The results presented here are preliminary but enlightening. However, the project is on going and data collection and analysis will be continued until the end of December of 2005.

Initial sampling and data collection was started in late January and early February of 2004. Soil samples are collected for texture analysis as well as other parameters of soil quality indexes (i.e., organic matter content).

As shown in figure 3, during the dry season almost all the treatments behaved similarly and the amount of sedimentation was at minimum. It is worth mentioning that the Vetiver grass had been planted in late December of 2003 and was not fully established until late April 2004. The small amount of sediment that was produced from the plot with Vetiver grass was mainly due to tilling that was done prior to planting. In general, not much sediment was produced from any of the treatment plots from February 2004 to June 2004 mainly due to low rainfall through out the dry season. As shown in Figure 3, the average rainfall for the month of June was 29 inches. It was during this time that Vetiver grass proved to be the most effective in sediment trapping by producing 0.23 t/ha of sediment per month from that major storm event as compared to plot with "Bare surface" or no cover condition that produced 7.3t/ha per month from a major storm event. The same trend was shown for the month of July and August and it is expected to continue through out the wet season (June- January 2005). It should be mentioned that although the amount of rainfall was lower in August the sedimentation was considerably higher from the “Bare surface” treatment plot due to the higher intensity of this storm event. Again it was shown (Fig. 3) that the “Vetiver grass” treatment was the most effective in sediment trapping as an erosion control during a major storm event. A similar trend is shown with turbidity where the water sample collected from the plot with “Vetiver ” had the least turbidity as compared to “Bare” surface condition (Fig. 4).

Preliminary results thus far have shown that Vetiver technology effectively reduced the amount of sedimentation as compared to plot with bare soil surface and/or other plots with different treatment at the watershed under study. The preliminary result from this study thus far has shown that Vetiver grass not only is an effective measure for erosion control but also improves water quality down the stream, hence protecting coral reef from muddy waters in southern Guam. In short as described by Xia and Shu (2003), Vetiver grass, due to its unique characteristics, such as higher biomass, fast growth, strong root system, higher metal tolerance and uptake ability, has been documented to play an important role in reducing soil erosion as well as for reclaiming degraded land for sustainable development and environmental integrity.

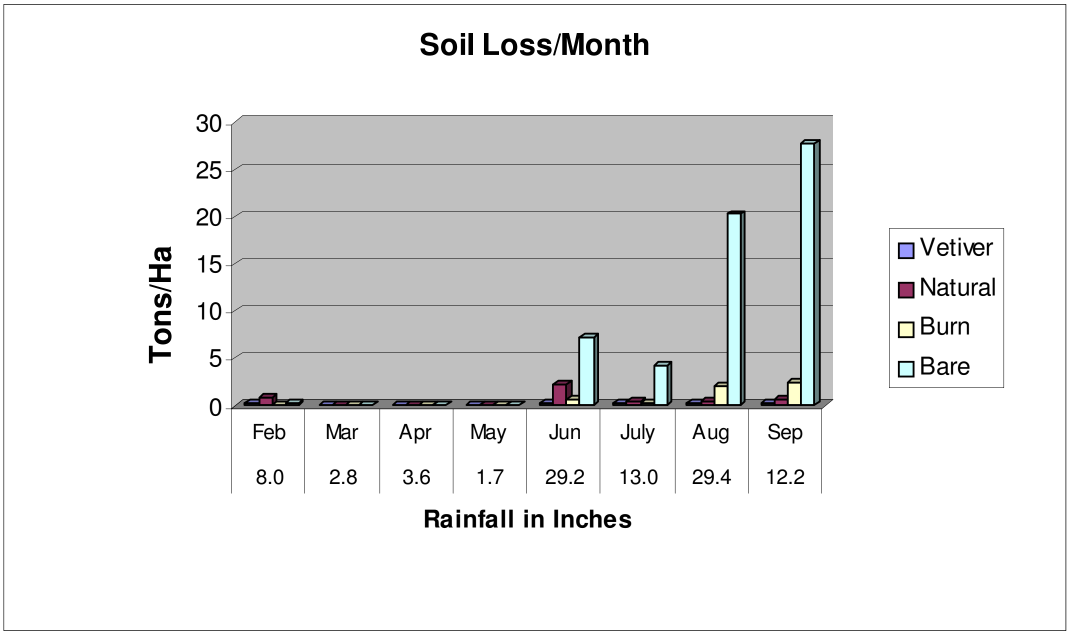


Fig. 3: Average monthly sedimentation from plots with different treatment.

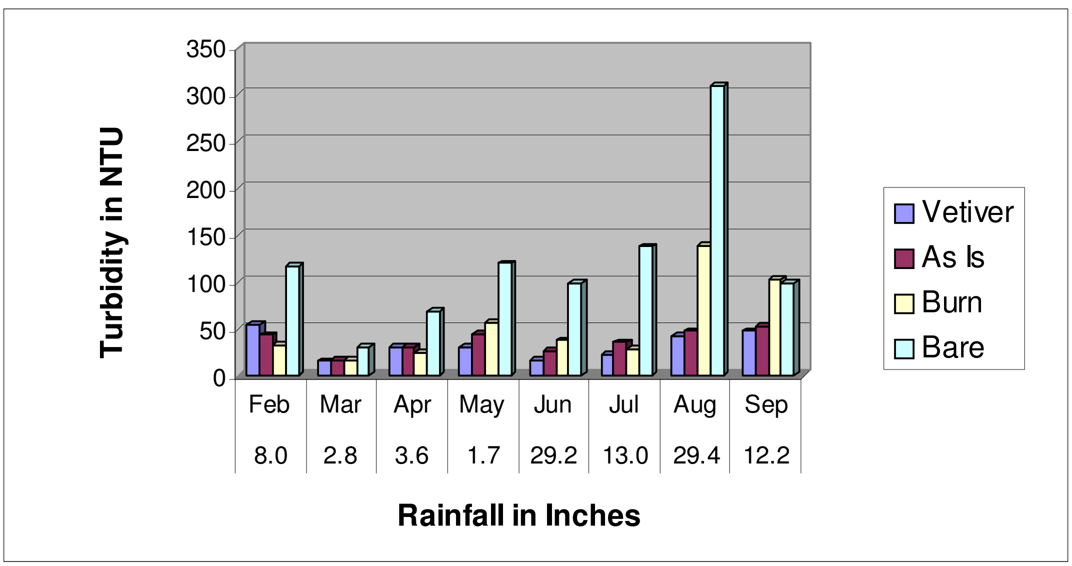


Fig. 4: Average monthly turbidity measurement from plots with different treatment.

Concluding remarks and recommendations

As indicated in the case study 1, the composted organic wastes are generally rich in organic matter and they improved physical as well as chemical properties of the soil under study. For sustainable agricultural systems within small-scale farming in the Pacific Islands, composting can be a viable option for developing effective plant nutrient management strategies in many situations. However, the real or perceived economic incentives to use composted organic material as a soil amendment need to be introduced with greater emphasis among the small scale farmers of Guam and the other farmers in the Pacific and Asian regions with similar environmental conditions. Our preliminary findings clearly indicate that productivity can be enhanced due to improved soil quality by proper use of composted organic materials, and that the environment benefits as well through the reuse of organic wastes that otherwise would be buried in the landfills.

Preliminary results from case study 2, thus far has shown that Vetiver technology effectively reduced the amount of sedimentation as compared to plots with bare soil surface and/or other plots with different treatment at the watershed under study. The preliminary result from this study thus far has shown that Vetiver grass not only is an effective measure for erosion control but also improves water quality down stream, hence protecting coral reef from muddy waters in southern Guam. In short as described by Xia and Shu (2003), Vetiver grass, due to its unique characteristics, such as higher biomass, fast growth, strong root system, higher metal tolerance and uptake ability, has been documented to play an important role in soil erosion as well as for reclamation of degraded land for sustainable development and environmental integrity.

In summary, the sustainability of natural ecosystems and environmental integrity cannot be maintained with the continuous nutrient depletion of the soil; sever erosion; land degradation; and environmental damages. It is time to re-examine the means by which we deal with land degradation especially in the most populated regions of the world in Asia and in the Pacific. These case studies presented here clearly showed that agricultural sustainability as well as watershed management for natural resources restoration and environmental protection is achievable if the techniques described are implemented properly.

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Table 1. Some of the characteristics of compost at the time of application

Compost Application Phase	pH	Moisture Content (%)	Carbon Content (%)	Total N (%)	C/N Ratio	Nitrate (NO_3) (ppm)	Phosphate (PO_4^{-3}) (ppm)	Potassium (K) (ppm)	Calcium (Ca) (ppm)	Magnesium (Mg) (ppm)
Nov 2003	7.27	49.6	25.1	0.672	37.4	231..5	162.7	5362.1	3672.3	1174.6
April 2004	7.48	50.3	29.5	0.618	47.7	173. 8	151.94	4761.2	5612.4	9840.4

Table 2. Measured soil parameters after different rates of compost application – April/May 2003

Compost Application <u>Rate</u>	pH	Bulk density (gm/cm^3)	Moisture Content (%)	Organic Matter (%)	Nitrate (NO_3)	Phosphate (PO_4^{-3})	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	CEC (meq/100g soil)
					(ppm)					
0 t/ha	8.0	1.18	26.01	5.36	32.8	30.09	206.83	3416.17	171.40	1.90
5 t/ha	7.6	1.01	25.86	5.64	49.6	52.34	744.97	3779.88	297.59	2.33
10 t/ha	7.6	0.98	28.07	6.57	58.9	61.02	1053.36	4748.70	431.20	2.98
20 t/ha	7.7	0.91	32.16	9.46	160.1	76.65	1418.71	5492.18	787.92	3.77

Table 3. Measured soil parameters after different rates of compost application – Nov/Dec 2003

Compost Application Rate	pH	Bulk density (gm/cm^3)	Moisture Content (%)	Organic Matter (%)	Nitrate (NO_3)	Phosphate (PO_4^{-3})	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	CEC (meq/100g soil)
					(ppm)					
0 t/ha	7.9	1.03	37.59	3.43	13.3	17.82	217.03	3178.61	182.63	2.17
5 t/ha	7.8	0.98	37.70	4.56	41.8	35.83	485.40	3300.61	337.88	2.62
10 t/ha	7.8	1.03	40.54	5.43	57.6	44.63	748.54	3495.12	511.26	3.24
20 t/ha	7.6	1.01	44.60	7.18	79.3	58.43	1064.72	4312.43	807.02	4.16

Table 4. Measured soil parameters after different rates of compost application – April/May 2004

Compost Application Rate	pH	Bulk density (gm/cm^3)	Moisture Content (%)	Organic Matter (%)	Nitrate (NO_3)	Phosphate (PO_4^{-3})	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	CEC (meq/100g soil)
					(ppm)					
0 t/ha	8.2	1.16	34.11	2.78	9.8	18.93	390.41	3694.64	172.66	2.09
5 t/ha	8.0	1.04	39.18	5.52	16.6	42.43	859.30	4875.00	375.42	2.97
10 t/ha	7.9	1.02	44.64	7.40	22.9	57.68	1265.0	5608.87	601.48	3.63
15 t/ha	7.6	0.99	42.77	10.3	88.0	64.69	1950.2	5835.57	849.49	4.12