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CHAPTER 11

SOIL AMENDMENTS FOR INCREASED AGRICULTURAL OUTPUT

Phal Mantha and Paul Sturm, Ridge to Reefs, Inc.

Introduction

As highlighted in earlier chapters, the geology, landscape, and soils of Palau are very diverse and varied, with soil scientists identifying over 32 major soil types (NRCS, Soil Survey). Due to this reason, and a confluence of other factors, agricultural production in Palau is faced with a variety of challenges. The prevalence of steep slopes (60% of soil types have slopes of 30% or more), weathered and erodible soils, high aluminum saturation, and soil acidity further exacerbate this situation. In addition, “Palau is highly vulnerable to sea level rise and on-going climate extremes due to El Niño– Southern Oscillation (ENSO) events” with “the frequency and intensity of extreme climatic events (particularly extreme high tides) expected to increase under the pressures of climate change.” (Taro, PACC Food Security Project).While historically, traditional agriculture and fishing supported a large population, Palau currently imports almost 85 % of food products consumed. In 2010, this cost over $24.5 million and accounted for 10 percent of total GDP. Though these factors pose considerable environmental, economic, and food security challenges, there are practical solutions that can be utilized in order to overcome these challenges and achieve increased agricultural output in Palau.

The creation, commercialization, and widespread application of low-cost, locally-produced soil amendments represents one of these solutions. When paired with soil testing and

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effective management protocols, local sources of biomass (including waste feedstocks) can be utilized to improve soil physicochemical and biological characteristics thereby (i) enhancing agricultural output (ii) increasing area suitable for agricultural management, and (iii) simultaneously reducing erosion and terrigenous impacts to coastal water quality. The soils on bottom lands (Mesei-Dechel-Ngersuul soils and Odesangel soils), most traditionally used for wetland taro cultivation, are rich in organic matter and suitable for agricultural production. It is reported that almost half of all taro production in Palau occurs in soils on these bottom lands. However, these traditional production areas are increasingly threatened by saltwater intrusion and "on average 6 % of taro production is lost each year due to saltwater intrusion." Therefore, the development of sustainable agricultural production systems in upland areas not impacted by high tide events or saltwater intrusion is all the more important for Palau's agronomic productivity and food security. The volcanic upland soils covering 61.8 % of Palau's land area, supported some of the earliest historical agricultural activities, as can be evidenced by the presence of anthropogenic agricultural terraces in these areas. Though the uppermost strata of "Aimeliik" soils in these areas have significant amounts of organic matter and low aluminum saturation, the Palau soils and Babelthuap-Ngardmau-Udorthents all have high aluminum saturation, placing an additional burden on agriculture and natural resource management. In this context, soil amendments represent an important suite of management tools enabling increased agricultural production in the dominant Oxisols of the volcanic uplands by favorably influencing soil pH and lowering the toxicity of soluble aluminum. Similarly, the addition of soil amendments and organic matter can help to alleviate pressures on Palauan agriculture in areas with infertile, saline, and acidic soils. The use of soil amendments in conjunction with cover crops and reduced tillage production methods can provide farmers and natural resource professionals with an effective suite of management tools which can be utilized to increase agronomic production; simultaneously combating erosion and soil loss at large landscape scales. These sorts of strategies are especially relevant to areas in Palau witnessing changing land uses and increased developmental pressures.

The local production of low-cost soil amendments can offer Palau many agronomic, economic, social, and educational opportunities. Adoption of this strategy has the potential to (i) enhance economic and food security by reducing dependence upon imported production inputs (ii) encourage the formation of local circular economies and sources of employment, and (iii) rapidly improve soil health and agronomic productivity while reducing erosion and sediment transport from managed areas. These solutions can also play an important role in reducing solid waste volumes and emissions of greenhouse gasses by diverting agronomically useful materials from landfills. In Babeldoab alone, household waste is comprised of 14 % green waste and 41 % vegetable/kitchen scraps and putrescible wastes (Palau Integrated Waste Strategy, 2017). In fact, the total weight of waste recorded at M-Dock National Landfill in 2005 was 23,810 kg or 52,382 lbs. per day. As cited in the Palau Integrated Waste Strategy publication, "compostable waste materials contribute about 42% to the total waste stream… meaning that a total of approximately 10,000 kg of compostable materials are available to convert to compost or fertilizer every day… yielding an estimated 5 Tons of compost per day." Therefore, it is very feasible to convert these sorts of domestic and municipal waste feedstocks into high quality composts and soil amendments which are capable of rapidly improving soil health and agronomic productivity. Total yields could be made even higher than the figure cited above through the utilization of novel composting and bioconversion methods such as statically aerated "composting bioreactors" and anerobic "Bokashi" decomposition. Furthermore, the aggregation of suitable biomass and it's subsequent conversion to soil amendments can provide unique opportunities for employment, natural science education, and community involvement in agriculture and environmental restoration.

Locally Available Sources of Biomass with Agronomic Utility

The table below highlights locally available biomass sources with agronomic utility and describes viable use cases for their application in Palauan agriculture.

Local Biomass Source	Agronomic Utility	Use Case for Palau
Green Waste, Food Scraps/Kitchen Waste, Woody/ Carbonaceous Waste	Inputs for the local production of high-quality aerobic composts, anerobic "Bokashi" composts, pyrogenous carbon/biochar, and liquid fertilizers/bio stimulants; all of which have utility as low-cost soil amendments capable of positively impacting soil health, plant growth, and plant morphology.	Biochar, aerobic composts, and anerobic "Bokashi" composts can all be used to improve soil health. The supernatant from the fermentation process can also be used as a liquid bio stimulant.
Fish Viscera & Meat and Bone Scraps	Inputs for the local production of liquid protein hydrolysates, granular solid fertilizers, and nutrient-rich composts. Fish hydrolysate in particular can be applied as a "full spectrum" fertilizer capable of providing complete nutrition (in the form of macro/micro nutrients and trace minerals) required for plant growth.	FH can be used a drip irrigation injectable liquid fertilizer. It can also be dried and used a solid granular fertilizer containing all essential nutrients required for crop production.
Limestone and Coral Sand	Readily available source of calcium and an important amendment for buffering acidic soils commonly found in Palau.	These materials can be directly applied as a soil amendment to buffer acidic soils and provide calcium.
Aquaculture Waste	Solid waste streams from Aquaculture can be "upcycled" through aerobic conversion into high quality liquid fertilizers. Nitrogen mineralization can be maximized by optimizing the aerobic process conditions.	Liquid fertilizer resulting from the aerobic conversion of aquaculture waste can be diluted and directly injected into irrigation systems.
Crustacean Shells	Excellent source of nutrients such as N, P, Ca, and Mg. Provides abundant amounts of Chitin which improves soil health/biodiversity, plant growth, and plant resilience to biotic and abiotic stressors by imparting induced systemic resistance (ISR).	Powered CS can be directly applied to soils or composted to provide immediate fertility. They can also be hydrolyzed to create liquid fertilizers and bio stimulants.
Seaweed/Macroalgae (*Peyssonnelia spp., Dictyota spp.,Sargassum spp, Caulerpa spp.*)	Natural source of plant available potassium and trace minerals. Can function as a bio-stimulant enhancing growth and productivity and reducing biotic and abiotic stress. Alginates can function as chelators improving soil health, allowing for an increase in plant available minerals, soil aeration, and water holding capacity.	Dried Seaweed can be directly applied to soils or added to compost. It can also be hydrolyzed to create liquid fertilizers and bio stimulants.

Local Biomass Source	Agronomic Utility	Use Case for Palau
Azolla (*Azolla spp.*)	Azolla provides abundant amounts of organic matter and nutrients while replicating itself rapidly. It can be used as feed, fertilizer, and an input into the production of various composts, soil amendments, and bio stimulants. Azolla can be an important tool in increasing the soil carbon pool and sequesters large amounts of atmospheric carbon. The use of Azolla should be approached with caution as a non-native plant species though it has been used successfully together with rice production in Japan and many other countries.	Azolla can be directly applied to soils and composts. It can be used as a feed source for a variety of animals and can also be used as a green manure crop.
Spent Brewers Grain and Brewery Waste Yeast	SBG's are a rich source of organic matter, macro/micro nutrients, and plant growth promoting vitamins such as B-1 (Thiamine). SBG's can be used as a standalone soil amendment to provide organic matter and plant available nutrients. SBG when applied in the form of aerobic or anerobic composts have been found to increase plant growth and yield in addition to reducing detrimental impacts from abiotic stressors. Brewers Waste Yeast can function as a low cost microbial stimulant and has a number of agronomic benefits.	SBGs can be dried and inoculated EM-1 to create a bokashi starter culture. They can also be used directly as a soil amendment or feed source.
Poultry Manure, Feathers, and Eggshells	Composted poultry manure, feathers, and eggshells have the ability to provide balanced nutrition and organic matter to plants as they contain " all the essential nutrients required for crop production." (UGA bulletin 1245).	These materials can be applied directly to soils or added to composts.
Untreated Cardboard, Paper, Municipal Carbon Sources	These municipal carbon sources can function as an important carbon source and bulking agent for aerobic compost processes. They can also be directly added to soil as a source of organic matter and soil amendment capable of improving soil texture and tilth.	These materials can be added to composts to serve as a carbon source and bulking agent. T

The "upcycling" of green waste, food scraps/ kitchen waste, and woody/carbonaceous residues into valuable agronomic inputs has the potential to provide many benefits to agricultural operations in Palau. The recent conclusion of a long-term field experiment in Australia comparing compost treatment to conventional fertilization has demonstrated multiple benefits to crop yields and economic returns on over 10 commonly produced vegetable crops (Eldridge, 2018). These findings highlighted that compost addition delivered "benefit–cost ratios of 3.3" when compared to conventional fertilization, "indicating that this system could deliver economic benefits to growers as well as improve soil quality and the environment." Furthermore, it was found that "follow up large applications of compost generated more substantial yield increases in responsive vegetable crops and economic benefits."

Fig. 56:
Carbonaceous waste readily available in Palau. This material was aggregated by the local community in a hamlet in Airai state and is suitable for the production of a wide variety of soil amendments and fertilizers.

Fig. 57:
Aerobic compost produced at the Koror State Compost Facility. This traditional aerated compost is rich in organic matter and of good quality but it's production is quite labor and capital intensive requiring considerable operations and maintenance expenditure. (Photos by Phal Mantha)

Perhaps one of the most sustainable sources of biomass with wide ranging utility is Azolla. This symbiotic "superorganism", comprised of the macro symbiont Azolla (a floating pteridophyte) and the micro symbiont Annabena azollae (N2 fixing cyanobacteria), can fix up to 3 times the amount of atmospheric nitrogen as Rhizobium and other nitrogen fixers commonly associated with legumes (1100 Kg Nitrogen per hectare vs. 400 Kg. Nitrogen per hectare). Azolla generates an enormous amount of biomass (35 to 40 tons/ hectare/year), doubling its mass every 1-2 days. It can be grown in both fresh and brackish water on non-arable land and can even be produced using waste streams such as manure and manure wash water. It is a rich source of protein (and therefore, plant available amino nitrogen) and can be used as a feed for livestock and aquaculture production as well as a fertilizer and bio stimulant with great agronomic utility. Azolla production is a carbon negative process capable of sequestering up to 55 tons of CO2/ha/yr. Furthermore, Azolla may be a suitable candidate to integrate directly into wetland agricultural production systems for crops such as rice and taro due to its ability to provide abundant amounts of atmospheric nitrogen, organic matter, plant growth promoting compounds, and weed suppression.

Fig. 58:
Azolla is commonly produced in shallow pits lined with an impermeable liner.

Fig. 59&60:
Azolla immediately after harvest. This material can be added to composts, used as feed, and directly applied to the soil as a soil conditioner. (Photos: Azolla Foundation)

In addition to various types of compost generated from green waste, food scraps, and azolla, wood waste from invasive species and other cellulose rich materials also have the potential to be converted into quality soil amendments. It is feasible to convert this waste into pyrogenous carbon, colloquially known as "biochar". Biochar has the ability to "improve soil water retention, cation exchange capacity, the content of different nutrients, and reduce soil bulk density and N leaching", all of which are outcomes beneficial to agronomic production (Cao, et al., 2019). Biochar can also "enhance the uptake of N and other nutrients by improving the root development and the whole plant physiological status. (Backer, et al., 2017). Based on 103 independent statistical analysis studies, Liu et al. have demonstrated that crop productivity was increased by 30% with biochar application to acidic soils (pH<5). These findings, in particular, are highly relevant to agriculture in Palau due to the prevalence of acidic soils and consequently, phytotoxic levels of soluble aluminum. The images below depict a low-cost and environmentally friendly production method for biochar in Palau.

Local woody waste including tree trimmings, untreated wood scraps, bamboo, and coconut husks can be sun dried by the "cover and dry" method i.e. they should be covered overnight and before, during, and immediately after precipitation events. Once dried to an ideal moisture content of 10-18 % (as can be measured by a low-cost digital wood moisture meter), the feedstock material can be made to undergo pyrolysis which is it's thermolytic decomposition in an oxygen limited environment. A small pit (1 meter x 3 meters x1 meter) is excavated in the ground, and the dried feedstock is loaded into the pit in a manner that ensures a consistent rate of pyrolysis. This is done by ensuring that the feedstock is a consistent size and shape. When dealing with uneven feedstocks, it is important to process them until they are as consistent as is practically feasible. The largest pieces of feedstock should be placed at the bottom of the pit and the smaller or thinner pieces positioned at the top. The reaction is started by lighting a fire from the top of the pit; therefore it is a "top lit" burn. This ensures that the reaction starts from the top and moves to the bottom of the pit at a relatively even rate. It can be said that this biochar production method is very environmentally friendly as most of the oxygen and combustion byproducts such as ash and volatiles are almost completely consumed by the "flame-cap" layer above the pyrolysis layer. In fact, if properly managed, little to no smoke is released during production and only

Fig. 61, 62, 63, and 64:
These images depict the local production of biochar in Palau's Airai State. They show the biochar pit after excavation, upon completion of loading of the feedstock material, the reaction after pyrolysis is almost complete and the feedstock is ready to quench, and the resulting biochar after quenching with filtered rainwater. (Photos by Phal Mantha)

the "heat fumes" are visible. The key piece of information to remember is that woody material burns in 2 phases- (i) from woody material to red hot embers in the first phase (ii) and from red hot embers to ash in the second phase. For efficient biochar production, we must stop the reaction once all of the feedstock has reached the "red hot ember" stage. A small amount of ash evenly coating the feedstock is the indication that the reaction has reached this stage, and the embers can then be quenched with rainwater or filtered municipal water sources. In addition to quenching the material and ending the reaction, the steam produced at this stage serves to "activate" the biochar favorably altering the pore structure and consequently, the agronomic utility of the resulting product. Typically, 15 to 25 percent of the initial dry feedstock volume will be converted into biochar. As an alternative to the pit method, biochar can be made in kilns, metal drums, and other commonly available materials.

The conversion of fish viscera and bones into soil amendments and fertilizers represents a low-cost, effective solution for the generation of local agronomic inputs from unutilized/underutilized waste streams readily available in Palau. This material can be aerobically converted to create a nutrient rich and highly biologically active compost or it can be enzymatically hydrolyzed to create a potent liquid hydrolysate fertilizer. The stabilized liquid hydrolysate has a shelf life of up to 2 years, can be used at all stages of plant growth, and can also be applied as a foliar nutrient solution. Fish hydrolysate can provide all of the essential nutrients required for plant growth and simultaneously acts as a

Fig. 65 & 66 :
The image on the left depicts a cone kiln, commonly used to produce biochar at small scale. This style of kiln works with cross current flow that generates counter current vortex flows- making for a clean, low-emissions process. The image on the right depict biochar production in Japan in a kiln made by the Moki Company. These sorts of kilns offer small farmers a low-cost solution to make significant quantities of biochar from commonly available materials.

powerful soil conditioner. If a solid compost product is desired, the fish waste (including bones) can be ground with a blender or shredder and then mixed with a suitable carbon source (at a ratio by volume of 1 part fish waste to 7 parts carbonaceous material) and aerobically composted in a traditional manner. The addition of compost as an inoculum for this process can speed up the conversion of fish waste into a usable product. Alternatively, the optimal method for production of this kind of product is in a statically aerated composting system or "composting bioreactor". The relevant production methods are detailed in a subsequent section of this chapter headlined "Fungal Dominated Composts". The pictures below illustrate key steps in the aerobic conversion of fish waste into a rich compost product.

Liquid fish hydrolysate fertilizer can be easily produced by a simple enzymatic hydrolysis process using locally available feed stocks and inputs. Papaya fruit (particularly overripe or fallen fruit) has abundant amounts of sugars and contains the proteolytic enzyme Papain. This papain helps to convert the proteins in the fish waste into the plant available amino nitrogen form and additional peptides while the sugars in the fruit provide a carbon source for other microorganisms that assist in the hydrolysis process. Alternatively, liquid fish hydrolysate can be manufactured utilizing a local sugar source such as molasses, sugar cane vinasse, or brown sugar/jaggery and a simple Lactic Acid Bacteria solution derived from rice wash and milk. In this variation, the Lactic Acid Bacteria and their respective exudates break down the fish waste into a plant available liquid fertilizer. First, the

Fig. 67:
Fish waste donated by NECO marine, a local Palauan company, was made to undergo preliminary degradation (in 3-4 days) by the addition of enough compost to thoroughly cover the material. Covering fish waste with compost and a carbon source is also a low-cost strategy to reduce putrefaction and jump start it's conversion into a usable agronomic product when refrigeration is not a viable option.

Fig. 68 & 69:
The partially degraded fish waste depicted in Picture 7 was mixed with wood chips derived from local tree trimmings and aerobically composted in the compost shed shown in Picture 9, resulting in a quality fish compost product. (Photos by Phal Mantha)

fish waste should be ground down or shredded and then evenly mixed with 3 times the volume of rainwater or non-chlorinated municipal water. In this example, 1 liter of fish mince would be mixed with 3 liters of water. Then, a local sugar source comprising 1/3rd the initial weight of fish mince in the mixture should be added to the water/fish mince mixture and thoroughly blended. For example, a mixture starting with 750 grams of fish mince would use 250 grams of molasses or a similar local sugar source. Finally, a lactobacillus serum (produced using rice wash and milk) or kimchi/sauerkraut fermentation liquids are added to the mixture at a ratio of 2 tablespoons lactobacillus serum for every 1 liter of the fish mince, water, and sugar mixture (i.e. 30 mL serum is added for every 1000 mL of the mixture). This mixture should be poured into a bucket with a fermentation airlock lid and placed in a shaded, dark location for 2-3 weeks until the process is complete. Once the fermentation is complete, the mixture should have no pungent aromas, and instead should have a slightly sweet, vinegar-like smell mildly reminiscent of alcohol or sake. Completion of the hydrolysis process can also be verified by testing the pH of the mixture. Once the pH has dropped to a stable range around 4.5, the process can be considered as completed. This mixture can then be used "as-is" or further shelf stabilized by the addition of phosphoric acid, bringing it to a final pH of 4. If desired, the resulting liquid can be filtered through a 150 mesh screen, allowing it to be injected into most standard drip irrigation systems. The solids resulting from the filtration process can either be composted or directly land applied as a solid fertilizer.

Fig. 70:
The set of images on the left, collectively referred to as Picture 15, depict different steps in the production of a liquid fish hydrolysate fertilizer. In this example, the hydrolysate is produced in commonly available "food safe" 5 gallon HDPE buckets with the fermentation airlock clearly visible. Large quantities of fish hydrolysate can be produced by farmers in a relatively short amount of time.

Application for Hydrolysate	Application Rate	Application Frequency
Foliar Spray For Field Production	1-1.5 gallons/acre or 1/2 cup per l1000 sq.ft dependent upon soil and tissue analysis.	Every 5-8 weeks as indicated by soil / tissue analysis
Direct Fertigation For Field	2-3 gallons/acre or 1 cup per 1000 sq.ft dependent upon soil Production and tissue analysis.	Every 5-8 weeks as indicated by soil/ tissue analysis

Fig. 71:
This table shows application rates for fish hydrolysate fertilizer; both as a foliar spray and in direct fertigation application.

Fungal Dominated Composts

The agronomic and ameliorative benefits associated with compost and organic matter application to soil are well documented in practice, scientific literature, and in earlier chapters of this publication. While conventional aerobic compost has the potential to be an excellent soil amendment, it's production is often capital and labor intensive. Managing a traditional aerobic composting process requires maintaining precise control over many variables such as temperature, moisture content, and air exchange; requiring operators to turn the materials frequently. Therefore, these systems often require specialized machinery, infrastructure, and operators; adding significantly to the capital and operational expenditure associated with their operation. This results in significant barriers to entry and prevents the widespread adoption of composting in some scenarios. Furthermore, the frequent turning of biomass which is required with these systems inhibits the formation of fungal hyphae and favors the formation of a bacterially dominated compost. A highly effective alternative to conventional aerobic composting systems are passively aerated static composting systems, including "composting bioreactors". The "Johnson-Su Bioreactor" and it's associated "Biologically Enhanced Agricultural Management" protocols (combining the use of multi-species cover crops with BEAM compost soil amendments) represent a significant evolution in the utilization of low-cost methods and local waste streams to rapidly improve soil health and agronomic productivity.

Benefits of Johnson-Su Bioreactor Compost:

- Increases soil carbon sequestration
- Increases crop yield
- Increases soil nutrient availability
- Increases soil water-retention capacity
- Produces biologically diverse compost
- Produces nutrient-rich compost
- Results in a low-salinity compost
- Improves seed germination and growth rates

Benefits of Johnson-Su Bioreactor Composting System:

- Reduces water usage up to six times
- Reduces composting labor time by 66 percent
- Requires no turning and little manpower
- Is a low-tech process that can easily be replicated
- Can be made using a diversity of compost materials
- Produces no odors or associated insects
- Materials generally cost less than $35 USD and can be used for up to 10 times
- No leaching or groundwater contamination

Analysis of BEAM transitioned soil has found a 4 times increase in microbial diversity and a 23 times increase in fungal mass. The diverse microbial communities identified have many important agronomic functions including- nitrogen fixation (free living and symbiotic), nitrogen cycling, carbon cycling, metal oxidation, phosphorous solubilizing, antibiotic producing, biofilm/quorum sensing, CO oxidation, pesticide/xenobiotic degradation, and phytohormone production.

Fig. 72, 73, 74:
Depending on the feedstocks that are composted, the finished BEAM compost material can have a clay-like consistency and is highly fungal dominant and microbially diverse. It can be applied directly to soil, via seed coating, or as a liquid extract at planting. The image in the middle shows that even at the higher application rates, only a relatively small amount of BEAM compost is used. The image on the right depicts finished material from a different batch of compost. (Photos by Dr. David Johnson)

Research conducted by Dr. Johnson and his colleagues have found enormous increases in total plant biomass and crop yields (doubling of plant growth compared to application of 8 other conventional composts) associated with the application of BEAM compost. When the cause of these yield increases was analyzed in multiple trials and studies, 2 main factors (having nothing to do with N,P,K, or organic matter as would be generally expected) were identified. First, the yield increases were directly correlated to an increase in the Fungal to Bacterial (F:B) ratios of soil microorganisms. The soils managed with BEAM protocols had much higher F:B ratios and MNPP. Second, it was found that a much higher proportion of total energy captured during the photosynthetic process (3% in low organic matter bacterial dominant soils vs. 56% in BEAM soils) was found going to plant structures such as roots, shoots, and fruits. Therefore, it can be said that application of these sorts of high F:B composts increase the photosynthetic capacity of plants in the amended areas. A critical part of BEAM management protocols is the integration of multi-species cover crops with BEAM compost application. Combining cover crops with the application of high F:B composts has many key benefits. Root exudates supplied by the cover crop consistently maintain the high microbial diversity and fungal biomass that is seen in BEAM soils. In addition, the cover crop adds enormous amounts of organic matter and nutrients to the soil allowing for rapid increases in soil health that would not be possible otherwise.

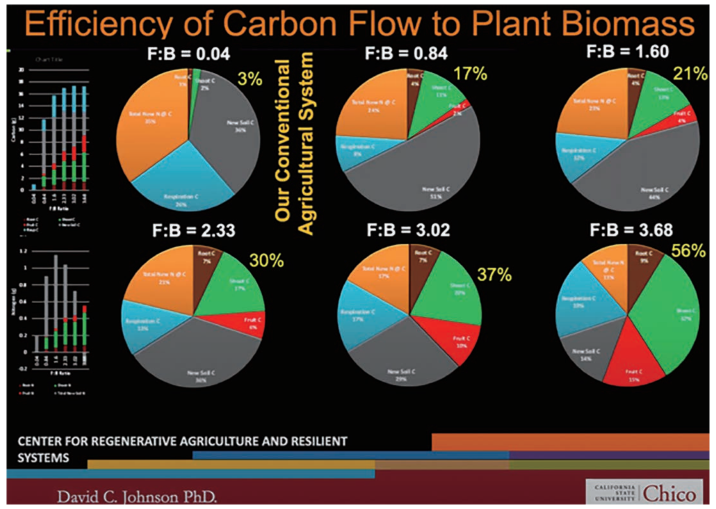

Fig. 75:
This chart shows a more efficient transfer of carbon from plant photosynthates to plant vascular structures and fruits as the F:B ratio of soil is improved as result of BEAM compost application.

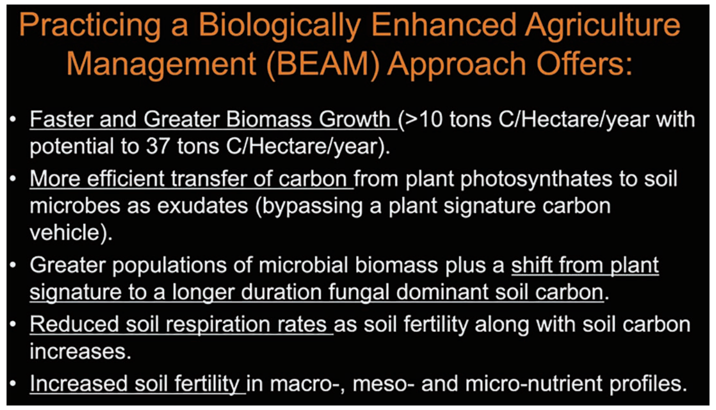

Fig. 76:
This slide highlights some of the benefits associated with practicing a BEAM approach. (Photos: Dr. David Johnson).

A "Johnson-Su" style bioreactor can be built with low-cost materials available from a hardware/home improvement store. Variations can even be built using waste materials such as pallets, scrap lumber, and scrap EMT conduit or rebar. Materials generally cost less than $35 each and last for 10 years or longer if properly maintained. 3 pieces of standard 5 oz. woven landscape cloth is required to form the external gas permeable skin for the composting bioreactor. One 13'x 6' section and two 6'x6' sections will be required. The supporting wire cage is built out of wire remesh (6" x 6" square 10 gauge) cut into a 5' x 12'6" section. This section can be folded into a cylinder (as shown in the photos below), secured with wire tie, and attached to the pallet base using screws or wire clamps.

Fig. 77:
This series of images depicts various steps in the construction, loading, and operation of the Johnson-Su composting Bioreactor. Once the feedstock material is loaded and has settled, the tubes can be removed

Pallets can be used as a low-cost base for these sorts of systems as they provide passive airflow through the individual slats. Four bricks (one for each side and levelled with each other) should be placed on the ground so as to raise the palette off the ground and promote further airflow. Holes are cut into the pallet and (6)- 6 ft. x 4" pipes are fixed into the holes before the bioreactor is filled with the feedstock. A simple perimeter irrigation system can be set up at the top of each bioreactor to maintain adequate moisture for the length of the composting process. A ring made of ½" irrigation hose joined together by a T-connector can serve as the main irrigation manifold and is placed above the feedstock material. Six "spot spitter spray sticks" should be plumbed evenly into the ½" ring and should be set on a timer to run for 1-2 minutes per day consistently keeping it at around 60-70 percent moisture. A key factor to remember when building a passively aerated static composting system is that the feedstock material should always be within 8-10 inches of an airshaft. This way, fresh air exchange will be provided to all of the feedstock material, preventing it from going anerobic and resulting in a quality finished product. A diverse array of feedstock materials can be used including green waste, coffee grounds/chaff, dairy or poultry manure, leaves, woodchips, and other carbonaceous materials. It is important to use a chipper/shredder to ensure that all the feedstock is thoroughly pulverized. This is especially important when tropical leaves. The original feedstock mix used by Dr. Johnson consisted of 1/3 by volume dairy manure, 1/3 leaves, and 1/3 woodchips. This recipe can be easily adapted to use materials commonly available in Palau.

Anaerobically Produced Soil Amendments

Some of the challenges associated with operating conventional composting systems have been highlighted earlier in this chapter. While passively aerated static composting systems offer a promising solution for the creation of high-quality soil amendments in Palau, there are also other low-cost solutions that can be utilized to achieve similar results. Kitchen scraps and other sources of organic matter can be anaerobically decomposed by lactic acid bacteria and other microorganisms yielding a solid soil amendment as well as a liquid leachate. " EM-1" (Effective Microorganisms) is a mixture of microorganisms containing lactic acid bacteria, yeasts, and phototrophic bacteria which was developed in 1980 by Dr. Teruo Higa of University of the Ryukyus in Okinawa. These synergistic organisms are used in a process called "Bokashi", which is very similar to pickling or creating silage for livestock agriculture.

In the Bokashi process,

> *"putrefying bacteria will be suppressed and, due to the fermentation action of EM, it is possible to manufacture compost with less turning than usual…compost fermented by EM is rich in amino acids and polysaccharides… EM prevents the production of ammonia during protein decomposition, metabolizing proteins in such a way that (plant available) amino acids are produced instead. Under normal circumstances, cellulose will be decomposed and broken down to form carbon dioxide. However, due to the fermentation action of EM, low-molecular polysaccharides will be produced and these will be absorbed by microorganisms and plants… plants can directly absorb amino acids from their roots, they can repurpose the energy that would have gone into producing amino acids and proteins, thereby producing fruit with more sugar."*

Because the Bokashi process is more like a "pickling" of the waste as opposed to a more volatile aerobic composting process, the resulting product tends to be higher in nutrient content. Unlike other composting methods, the Bokashi process allows for the conversion of waste from dairy, meat, and eggs into a usable agronomic product. EM can be used to suppress odors in animal production operations, reduce the germination of larvae and flies, and even improve the health of humans, animals, and livestock due to it's probiotic qualities. Therefore, EM can be an important tool for solid waste management, animal husbandry, aquaculture, environmental restoration/ water quality improvement, and sustainable agriculture. The supernatant of the Bokashi fermentation process, also known as "Bokashi Juice" or "Bokashi Leachate" is a powerful liquid fertilizer and bio stimulant which can be diluted and applied directly to plants.

The Bokashi method requires a starter culture which must be used during the waste conversion process. The original starter culture can be "subcultured" and replicated using a low cost sugar source to provide carbon to the microorganisms. This can be done if a liquid EM-1 product is desired. It is important to remember that only unchlorinated or filtered water is to be used for the sub culturing process. In other scenarios, a solid granular inoculant may be more desirable. This granular inoculant is referred to as "Bokashi Bran" and is simply the same consortia of microorganisms loaded onto a solid growth substrate along with a carbon source to make it shelf stable. Bokashi bran is generally made using low-cost or waste materials as the substrate for microbial growth. Rice hulls, rice bran, wheat germ, and wheat bran are typically used as the growth substrate. However, a variety of other materials including sawdust, shredded newspaper, shredded (untreated) cardboard, coffee grounds, coco coir, and spent brewers grains are all suitable to use as a growth substrate for producing the granular inoculant as well. Regardless of what materials are available and selected to function as the growth substrate, it is important to maintain a ratio 1:1:100 of EM:Molasses:Water in the solution that will be loaded onto the growth substrate. For example, 20 kg of dried growth substrate would be mixed with 4 liters of water, 40 mL of EM-1 mother culture, and 40 mL of unsulfured blackstrap molasses or a similar sugar source.

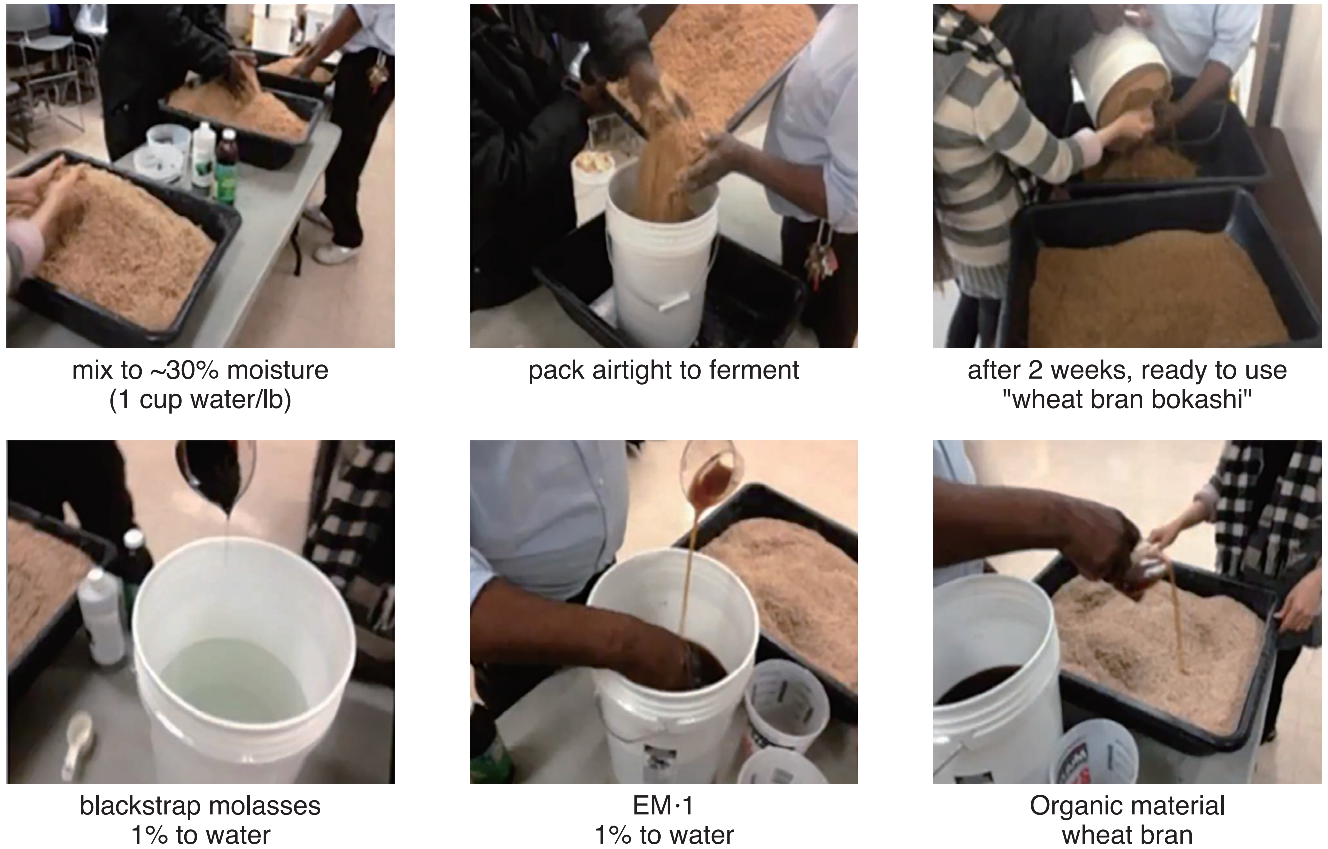

Fig. 78:
This series of images depicts successive steps in the creation of Bokashi starter compost using wheat bran, molasses, and EM-1 or Lactobacillus culture as the "mother culture".

The substrate is thoroughly mixed with this solution until it reaches field capacity. A minimum moisture content of 30% is required and 60-65% is ideal. This can be ascertained through the "squeeze test". When squeezed, the flakes should stick together without dripping solution. If it crumbles apart, the mix is too dry and if a significant amount of solution drips out when the mix is squeezed, it is too wet. If it is too dry more solution can be added and if it is too wet more growth substrate can be added and thoroughly mixed until it passes the "squeeze test". Once ideal moisture content has been reached, the mix should be tightly packed into a container and sealed to ensure there is no air exchange. It should then be placed in a warm dark place for 2-3 weeks after which the substrate will be thoroughly colonized by our consortia of Effective Microorganisms. This mix can then be air dried and sealed in a container in a dry place away from direct sunlight and can now be called "Bokashi Bran" that is ready to use.

Fig. 79, 80 & 81:
The image on the left shows the materials commonly used to create "Bokashi Bran"; rice or wheat bran, unsulfured molasses, and starter culture. The image in the middle depicts the ideal moisture content for creating Bokashi bran. This can be ascertained through the squeeze test as described above. The image on the right depicts the drying of the Bokashi bran in recycled food containers after the fermentation process is complete. (Photos by Rebecca Louie, from in the "Compostess Blog")

Once there is a sufficient supply of Bokashi Bran, the "anerobic lacto fermentation process" can be initiated, enabling the rapid conversion of kitchen/household scraps and other waste streams into valuable agronomic inputs. Roughly 25 lbs. (~11.3 kg) of Bokashi bran will be required per ton of waste, and the culture can be replicated to create additional growth substrate from local sources of biomass-resulting in significant cost savings. Furthermore, the fermentation chambers can be constructed with repurposed materials such as Intermediate Bulk Containers (IBC Totes), plastic drums/barrels, standard shipping pallets, and water/gas impermeable membranes such as visquine or HDPE. The main guiding principles for this process are that the container/fermentation vessel should be completely airtight, and allow for drainage of the "Bokashi Leachate" from the below the material that is being converted.

Fig. 82, 83, 84:
The image on left shows a Bokashi composting setup using plastic garbage cans as the fermentation vessels. The image in the middle shows a series of Bokashi composting vessels built out of pallets. The image on the right depicts larger scale bokashi composting using a silage tarp and silage style production methods. All of these methods are suitable for quickly producing large quantities of soil amendments because they successfully provide an anerobic environment for the inoculated biomass to undergo conversion.

The Bokashi bran should be evenly mixed into the biomass at the rate described above (25 lbs/ton), tightly packed into the fermentation vessel, and left to ferment for 3-5 weeks or until there are no putrid odors and a mild vinegar smell is present. For the conversion of large amounts of biomass, a silage tarp can be placed over the tightly packed and pre-inoculated biomass and then secured with sandbags filled with rocks, dirt, or sand to exclude air. This allows large amounts of biomass to be anaerobically converted into Bokashi compost, and is very similar to the process of creating silage where feed is fermented and anaerobically digested to increase palatability and nutrient content. This Bokashi composting process also yields a "liquid leachate" which can be used as a biofertilizer. While this leachate may not be adequate to use as a stand-alone fertilizer, it is excellent for providing supplementary plant nutrition and as an additive to compost teas and foliar feeding regimes. Once the fermentation process is complete, the Bokashi compost can be mixed into soil so that aerobic microorganisms can be activated and finish the final breakdown of the organic matter. The soil is suitable for planting 2-3 weeks after the Bokashi compost is mixed in. Anerobic decomposition methods such as bokashi and lactic acid bacteria fermentation can be effectively utilized at various scales including at the individual household scale.

There are many examples from around the world of successful community collection programs for kitchen scraps. If households are provided with a sealed container and Bokashi starter culture, instituting a waste collection and compost production program can be relatively straightforward. Inexpensive sealed plastic containers such as totes and 5 gallon containers can be distributed to households enabling easy collection and diversion (from the landfill) of this valuable waste. In this manner, large amounts of waste biomass can be quickly converted into high value soil amendments and used to improve agronomic productivity.

Cover Crops as a "Living Soil Amendment"

The effective use of cover crops and green manures have the potential to confer enormous benefits to agricultural and natural resource management in Palau. Unlike many types of commonly used soil amendments, cover crops and green manures can be grown *in situ,* eliminating the need for hauling and transporting large amounts of biomass. After initial planting, many green manure crops can be grown to maturity with the seeds being harvested, thereby eliminating the need for continual purchases of seed. Many green manure species can contribute up to, and in some scenarios more than, 50 Tons per hectare of organic matter to the soil in the first production cycle alone. This can rapidly increase soil organic matter, improve nutrient cycling, augment the pool of labile carbon in the rhizosphere, and improve soil biology leading to increased agronomic productivity. Soil cover provided by cover crops and green manures can dramatically decrease soil loss and erosion, increase plant available water, simultaneously out competing weeds and invasive species. This can allow farmers to reduce their dependence on (or even completely eliminate) the use of chemical herbicides. Furthermore, the use of cover crops and green manures are complementary to the use of reduced tillage or "no till" production practices. By allowing farmers to eliminate capital and labor intensive operations such as tillage and weeding, the use of cover crops and green manures allow smaller

Fig. 85, 86:
The image on the left shows plantain production integrated with a *Canavalia ensiformis* (sword bean) cover crop in Gurabo, Puerto Rico. Edible perennial cover crops such as dwarf pigeon pea (*Cajanus cajan*) may be suitable for similar integration into existing agricultural production systems in Palau.

non-mechanized farmers and farmers practicing agriculture on steep slopes to more effectively compete with imported produce offerings and larger mechanized farmers.

The integration of cover crops, green manures, and nitrogen fixing species into existing agriculture and agroforestry systems in Palau may confer significant advantages to farmers. In addition to providing valuable fodder for animal agriculture, some species are edible protein sources that can be directly integrated into existing production systems. For example, edible perennial cover crops such as dwarf pigeon pea (Cajanus cajan) can be integrated into a variety of different production models, generating large amounts of high protein biomass that is suitable for human consumption. Other species such as Native Palauan species as potential cover crop candidates. *"Kemairs"* grass and other viable species for local cover crop development in Palau.

Brief List of Non Native Cover Crops of Value- As a starter look at Hoolehua Plant Materials Institute publication on Pacific Cover Crop Species. Talk to Local Partners, Ann and Chris Kitalong, Bernie and Bola from PCS, perhaps other partners in the Pacific, Patrick Keeler, etc. for developing a final list of viable species and use cases.

Integration of edible cover crops into agricultural/agroforestry production (Dwarf pigeon pea or similar edible perennial species.

SOIL AMENDMENTS FOR INCREASED AGRICULTURAL OUTPUT CHAPTER 11

Indigenous Micro Organism based Soil Inoculants-

One paragraph summary of the agronomic benefit of using soil inoculants derived from IMO's

Brief Summary of Production methods with Figures.

Conclusion- Integration of Methods- Briefly describe the most efficient, practical, methods for integrating all of the strategies described above into useful low-cost/high return production systems and/or viable land uses- i.e soil amendments should be integrated with cover crops, and reduced tillage/conservation tillage management methods. Briefly touch on appropriate technology for the incorporation of soil amendments in a manner that minimizes soil disturbance (i.e power harrows, no till drills, and surface broadcasting). Illustrate with pictures relevant to both small scale and mid to large scale production.

Describe how can we study the changes brought about by soil amendment application through soil tests, microscopy, and other monitoring methods(ACE Protein Index, Metabolites, Genetic Markers, etc.) to gain a better picture of the microbial biogeography of different soils in Palau. Metatranscriptome analysis to gain an understanding of metabolic processes occurring in the soil. Why these methods are relevant in the face of pressures from development and changing land uses… recommendation that soil amendments and cover crops could be integrated into policy and/or incentivized for Palauan agriculture to rapidly improve soil health and reduce impact from development projects.

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